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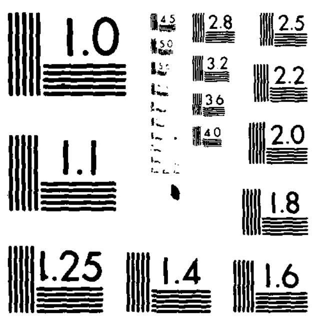

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FINAL TECHNICAL REPORT
GT PROJECT A–2550

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MARINE AIR TRAFFIC CONTROL AND LANDING SYSTEM (MATCALS) INVESTIGATION

By

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Prepared for

NAVAL ELECTRONIC SYSTEMS COMMAND
WASHINGTON, DC 20360

Under

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February 1982

GEORGIA INSTITUTE OF TECHNOLOGY
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Georgia Tech investigated several areas related to the development of the Marine Air Traffic Control and Landing System (MATCALS).

A television tracker system for the AN/TPN-22 radar was designed, assembled, and delivered. A cursor whose position is determined by the radar's tracking solution is superimposed on a TV camera image of the aircraft on its landing approach. Alphanumeric data also appear on the display for video tape documentation purposes.

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20. ABSTRACT (continued)

AN/TPN-22 radar-related tasks included investigations of multipath interference, gated automatic gain control (GAGC), and amplitude processing techniques. Multipath interference was determined to be a significant source of tracking error, especially for large longitudinal touchdown offsets. A special fence was designed and constructed for a planned experimental verification of these determinations at Patuxent NAS. GAGC characteristics were defined from measured system response data. The GAGC worked as designed, but exhibited drift characteristics which would adversely affect aircraft tracking accuracy. The most promising signal amplitude processing technique investigated ia a spatial filtering concept involving fitting a polynomial to the amplitude return versus beam position.

A baseline performance specification for the MATCALS airport surveillance radar (ASR) was generated, and detection range performance was determined for candidate radars. No radar evaluated meets the detection criteria over the MATCALS coverage volume. A modular, solid state transmitter should be adopted for the MATCALS ASR. A solid state AN/TPS-65 variant with a modified antenna is the choice of the systems evaluated for a relaxed set of performance specifications. The highest scoring radar beacon system is the Westinghouse antenna, Teledyne AN/APX-107 interrogator, and Sperry I-SRAP I target extractor.

PREFACE

The university associated participants in this investigation included the Engineering Experiment Station at the Georgia Institute of Technology in Atlanta, Georgia; the Engineering Experiment Station at Auburn University in Auburn, Alabama; and Flight Transportation Associates, Inc., in Boston, Massachusetts. Georgia Tech acted as prime contractor to the Naval Electronic Systems Command in Washington, D. C. under Contract No. N00039-80-C-0082. Auburn University and Flight Transportation Associates were subcontractors to Georgia Tech under Contract Nos. 1-A-2550 and 2-A-2550, respectively.

Dr. Robert N. Trebits served as Project Director, and Mr. Eric S. Sjoberg served as Associate Project Director of this investigation, designated Georgia Tech Project A-2550. Dr. Charles L. Phillips coordinated the Auburn University project activities, and Mr. William C. Hoffman coordinated the Flight Transportation Associates project activities. The Navy Project Engineer was Mr. Dan Brosnihan, who is also the MATCALS Program Manager.

This final technical report emphasizes the program activities performed during the latter part of 1981 by Georgia Tech. Separate reports were generated by Auburn University and Flight Transportation Associates to document their research efforts on this MATCALS program. The authors of this report include Dr. Robert N. Trebits, Mr. Eric S. Sjoberg, Mr. Raymond B. Efurd, Mr. Benjamin Perry, Mr. Mark A. Corbin, and Mr. Ramsay F. Hall. The technical guidance provided by NAVELEX personnel has been appreciated, with particular acknowledgement to Mr. Charles Gill, Mr. Daniel Brosnihan, and Mr. Richard Govoni.

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EXECUTIVE SUMMARY

This final technical report summarizes the major accomplishments on contract N00039-80-C-0082 from January 1980 through December 1981. Four tasks were defined for Georgia Tech under that contract: refinement of the statistical tracking error model previously developed by Georgia Tech; design and implementation of a TV-Tracker system to be installed at Patuxent NAS; technical assistance to NESEA; and investigation of the MATCALS ATC system including both ASR and RBS systems.

Statistical Tracking Error Model

Only a very limited amount of work was accomplished on the statistical tracking error task before technical redirection by NAVELEX. Computer model extensions and refinements accomplished prior to the redirection include improved target scintillation analysis, inclusion of rain clutter interference, and incorporation of the actual AN/TPN-22 antenna pattern.

The computer model continues to predict tracking errors greater than those derived from measured data, and the resolution of these differences was the major intent of this task. Because of redirection by the sponsor, this resolution was not completed.

Television Tracker

Under the current contract, Georgia Tech defined and implemented a TV-Tracker for the MATCALS test facility. The tracker's purposes are to: (1) provide an instantaneous visual representation of the track quality of the TPN-22 radar, (2) contribute to range safety by making possible visual observation of the test site runway from an indoor operations center, and (3) provide an integrated record of test parameters, conditions, and results on video tape. Primary objectives to be met by the TV-Tracker are to: (1) superimpose a cursor upon a TV display of an airplane on approach, (2) move the cursor in response to changes in the tracking solution of the precision approach radar, and (3) include on the same display an alphanumeric representation of test run data.

The tracker system is operated from a CRT terminal (separate from the TV display) by entering commands via the terminal keyboard and is capable of updating the cursor position and test data display at least five times per second. Sixteen different cursor types may be selected. The tracker has a system tracking accuracy of ± one milliradian in azimuth and elevation. This accuracy is of the same magnitude as the specified tracking accuracy of the TPN-22 radar and will not distort the qualitative value of the radar error as observed on the tracker display. The system is designed to maintain target visibility from a range of four nautical miles to touchdown and to maintain stable calibration.

The TV-Tracker was installed in the TPN-22's computer and peripheral equipment area and is connected to the radar's UYK-20 computer via an 8-bit parallel data cable. Two cameras are used, one with a 150 mm telephoto lens for tracking at long range and another with a 50 mm wide-angle lens for tracking at near ranges to touch-down. A single camera mounted on a servo-pedestal was considered as one possible approach to implementing the tracker system, but this approach was discarded in favor of stationary cameras because the additional pedestal servo-loop errors would add to the radar tracking errors in the TV-Tracker display. The cameras are rigidly attached to the top of the TPN-22 antenna at its vertical center line and are aligned such that the 14 degree horizontal field of view of one camera and the 4.6 degree horizontal field of view of the other camera include all areas of interest on the test range.

The image from each camera is continuously displayed on video monitors. The cursor and test data are superimposed on one of two camera video signals, selected by the operator. The composite signal is then routed through a video tape recorder before being displayed on one of the monitors. The second monitor simultaneously displays the other camera's video without a cursor or alphanumeric data. The second monitor will be useful in determining an optimum point during a test run at which the track function should be switched to the camera with the wide angle lens.

The TV cameras, lenses, video monitors, video tape recorder, and interconnecting power and signal cables were all government furnished equipment. Georgia Tech supplied the TV Tracker computer, CRT terminal, floppy disk drives, hardware interface to the UYK-20, and a software user system which gives operator prompt messages describing each step in the calibration or track procedure.

Technical Assistance to NESEA

This task was included to permit Georgia Tech to investigate areas of high interest to NESEA test personnel at Patuxent NAS and to provide a contractual vehicle for quick technical response to changing needs. During the course of testing the TPN-22, it is probable that the test personnel will observe certain traits of the radar which demand improvement. The test center, however, does not have sufficient personnel to investigate many potential improvements. In this regard, Georgia Tech is able to study a problem theoretically and recommend action based on sound engineering judgement and an unbiased observer point of view.

Early in the contract period, NESEA listed three areas of high interest for Georgia Tech investigation. These included:

1. Multipath Investigation,
2. GAGC Investigation, and
3. Amplitude Processing Techniques.

Georgia Tech initially agreed to investigate the first two areas. During the course of the project, the GAGC study evolved into an amplitude processing investigation. Georgia Tech designed a test flight program to gather data to complete the investigations. The following paragraphs summarize the progress made on these tasks.

Multipath Interference Investigation - The TPN-22 Precision Approach Radar (PAR) system is designed to automatically track and land aircraft from a distance of 10 nautical miles to within 300 feet of touchdown. In certain landing scenarios, the radar is required to perform very low angle tracking. The low antenna height and high reflectivity of the runway cause multipath interference effects that are a source of tracking error, both at long ranges and just prior to touchdown. The multipath problem was analyzed to determine the tracking situations affected, the magnitude of the effect, and potential methods of reducing the multipath associated errors.

The multipath analysis revealed that this source of tracking error will be significant only when the tracking angle is low enough to cause the main beam to intersect the ground when determining the lower target edge. The other three edges of the cross pattern will not be affected by multipath in any anticipated scenarios. Geometrically, the tracking angle from the radar to the target at which multipath

becomes significant is between 0.83 and 1.2 degrees, depending on the longitudinal offset of the landing point to the radar. This result is at variance with experiments previously reported by ITTG. Measured data from the ITTG Mode 1 Phase 2 report, however, seem to verify the Georgia Tech analysis. Serious signal-to-noise ratio (SNR) degradation will occur when the aircraft is at long ranges or within five seconds of touchdown. Of equal importance, the direction and magnitude of the tracking error is strongly dependent on the longitudinal offset, antenna height, surface (runway) tilt, and glideslope.

Various methods of reducing the multipath interference effects were investigated, but only one appears feasible: the use of special purpose fences placed on the runway apron to obstruct the reflecting surface.

The potential gains and losses in SNR resulting from the employment of such multipath fences were calculated as a function of various parameters, including aircraft glideslope, longitudinal landing point offset, fence height, number of fences, and fence location. The analysis indicated that a single fence approximately 3 feet high will considerably reduce interference from multipath for a 750 foot longitudinal offset. However, as the landing point offset is increased to 1500 feet, the multipath interference becomes more severe, and the effectiveness of obstructing fences is reduced. We found no combination of fences that could sufficiently reduce multipath interference in this long offset scenario.

GAGC and Amplitude Processing Investigation - The objective of this investigation was to determine if the Gated Automatic Gain Control (GAGC) implementation in the AN/TPN-22 is optimum and, if not, how performance improvements might be accomplished. From documentation reviews, test results, and conversations with ITTG and NESEA personnel, four conclusions become apparent:

1. A GAGC is required to avoid saturation of subsequent circuits.
2. The present GAGC does not adequately normalize the return signal video level for use with a constant threshold.
3. The GAGC implementation is working as it was designed to function.
4. Therefore, the present GAGC design will not provide the required performance.

Using these conclusions as a basis, and noting that a GAGC is required to satisfy (1) above, an investigation plan consisting of four elements was established:

1. Measurement of the GAGC transfer curve.
2. Study of alternative signal processing techniques.
3. Algorithm development and simulation of various centroid techniques.
4. Evaluation of the processing algorithms with real flight test data.

The first three parts of the investigation were essentially completed with some unexpected results. The fourth part was not completed, due to aircraft malfunction and scheduling conflicts at Patuxent NAS.

In May, 1980, the GAGC transfer curve measurements were made at Patuxent NAS. The gross test results agreed well with results from earlier tests made in August, 1979. Further analysis, however, revealed a time varying error whose source seems to be the GAGC circuit itself. Further tests to determine the source of this discrepancy are required so that this potentially major error may be eliminated.

Amplitude Processing Techniques - Several amplitude processing concepts were investigated. The most promising of these is a spatial filtering technique that filters the received signal data with no loss in system bandwidth. The technique involves fitting a second order polynomial to the return signal amplitude versus track arm position. Preliminary analysis indicated that this method could provide very promising results, but the analysis should be verified with flight test data.

Airport Surveillance Radar Investigation

A baseline specification for the MATCALS ASR was synthesized from Specific Operational Requirement 34-22, accepted radar system handbooks, material resident at Georgia Tech, and conversations with NAVELEX, NESEA, and Marine Corps representatives. The parameters defined by this baseline specification were incorporated into Georgia Tech's radar range performance computer program MRANGE. Rather than create a separate computer program for each radar implementation, we used a single program for performance evaluation. Radar system variances from a "standard" configuration were modeled as necessary to fit the program requirements, while maintaining detection performance equivalent to that provided by the "standard" configuration.

System data on U.S. made airport surveillance radar systems, both commercial and military, were collected. These data included specified system performance

parameters, transmitter characteristics, receiver characteristics, physical characteristics, and reliability/maintainability characteristics. These data were tabulated by system and category for comparison. Aircraft detection performance for each system configuration was computed as a function of range, for a 1 square meter cross section target flying toward the radar at a constant altitude. Antenna beamshape, multipath interference, rain backscatter, target scintillation, and atmospheric absorption effects are all represented in the calculated detection performance curves.

None of the radar systems investigated met the MATCALS detection criteria throughout the specified coverage volume. In addition, none met a relaxed set of detection criteria over the original MATCALS coverage volume: 80 percent detection and a 10^{-6} false alarm rate.

The GPN-24 and TPN-24 do not have sufficient detection range in clear air and fare worse when forced to use circular polarization for rain backscatter rejection. The TPS-44 has better range performance than the previous two candidate systems and is configured for tactical operation, but has no rain backscatter rejection capability whatsoever. The TPS-65 has almost adequate range performance, but is susceptible to target fallout due to multipath interference effects that are most severe at 10,000 foot aircraft altitudes.

Georgia Tech recommends that the MATCALS airport surveillance radar performance specifications indicate an 80 percent detection probability and a 10^{-6} false alarm rate over 60 nautical miles of range. Elevation angle coverage between 1 and 30 degrees and an altitude ceiling of 30,000 feet are adequate for the MATCALS terminal area surveillance radar system.

Georgia Tech further recommends that the MATCALS ASR include a modular, solid state transmitter, typified by the TPS-65 variants. Such a transmitter offers graceful degradation characteristics, do not need water cooling, and may not need full redundancy to meet FAA certification for CONUS operation. If the antenna characteristics of the TPS-65 with 50 kW solid state transmitter were modified to mitigate multipath interference susceptibility, that system would clearly be the choice of those systems evaluated.

Radar Beacon System Investigation

The Air Traffic Control Radar Beacon System (ATCRBS), also known as Identification Friend-or-Foe (IFF), was first developed and used by the military in World War II. Since then, IFF has been expanded and improved, and both the military and civil sectors currently rely on IFF information for air traffic control. The radar beacon system, consisting of a ground interrogator/receiver and an airborne transponder, has advantages over an airport surveillance radar system in several areas, including target identification and three dimensional target position accuracy. In addition, because this system employs a transponder, the signal strength loss with range follows an R^2, rather than the R^4, law for radar. This one-way transmission property also effectively removes weather backscatter as a source of interference. Because of these advantages, IFF was designated by Specific Operational Requirement 34-22 as the primary air traffic control sensor.

The task concerning the role of ATCRBS in MATCALS was fourfold: (1) establish ATCRBS baseline requirements, (2) accumulate vendor product information on applicable off-the-shelf equipment, (3) evaluate this product information, and (4) evaluate product performance. For evaluation purposes, the IFF system was divided into three subsystems: antenna, interrogator, and target extractor. A quantitative evaluation was developed using weights for the various factors in the three subsystems. A listing of the manufacturers, products, and evaluation scores is given in Table 5.8 in this report.

The highest scoring antenna is the Westinghouse antenna, mainly because a common antenna is used for both the radar and beacon. If the Westinghouse system is not chosen, the next highest scoring antennas are the Hazeltine antennas, which are tactically configured, 14-foot antennas. The Teledyne AN/APX-107 scored the highest among the interrogators because of its extremely small size, but this interrogator is not currently deployed in a redundant configuration. More compatible candidates for the MATCALS mission are the Cardion AN/UPX-27, Hazeltine AN/TPX-54, and Westinghouse interrogators. The highest scoring target extractor is the Sperry Univac I-SRAP I, although the Cardion CTE-2 and Litton CV-3682/UPX score well. Scoring less favorably are the EATON/AIL TPX-42A VSP and Westinghouse DECU.

The Discrete Address Beacon System (DABS) was also examined for future MATCALS use. DABS is the next generation upgrade in ATCRBS and is intended to supply sufficient aircraft capacity and performance to meet air traffic growth well into the next century. Advantages of incorporating DABS into MATCALS include its

compatibility with current ATCRBS (for easier transition), over 16 million aircraft address codes, uplink and downlink information transmission, collison avoidance information, lower pulse repetition frequency, and significant improvements in both range and azimuth measurement. However, these DABS advantages are not realized without increasing ATCRBS system size and cost. The DABS system is estimated to cause the size and cost of an IFF system to increase by five to ten times.

Summary and Recommendations

The Georgia Tech MATCALS tasks divide naturally into two areas: the AN/TPN-22 improvement investigations and the air traffic control study. The major conclusion and recommendation for three of the Georgia Test tasks involving the AN/TPN-22 is that flight tests are required to bring these tasks to fruition.

The AN/TPN-22 statistical tracking error model predicts values consistently higher than those observed at the MATCALS test site. Flight test data will permit isolation of the error sources, establishment of absolute errors (using the laser tracker for the reference), and help in upgrading and validating the model itself.

The television tracker system was assembled, and all necessary software was implemented. System installation at the Patuxent NAS test site was accomplished, and NESEA personnel were trained in system use. The tracker system operates at a minimum update rate of 30 Hz. Evaluation during the flight test should establish the adequacy of this data rate.

Several significant conclusions were determined from the technical assistance to NESEA. Multipath interference appears to be a major source of tracking error near touchdown and at longer ranges, especially for large touchdown offsets from the radar. The gated automatic gain control implementation in the AN/TPN-22 exhibits significant drift which will affect tracking operation. Finally, received signal amplitude processing appears to offer improved aircraft centroid estimation over the edge track technique currently employed.

NESEA and Georgia Tech recommend that GAGC data recorded during the recommended flight tests be used to determine the effectiveness of the multipath interference fence and to develop amplitude processing techniques. The best candidate processing technique should then be identified and optimized for implementation in the AN/TPN-22 system.

The air traffic control task addressed both the airport surveillance radar and the radar beacon system. Of the U.S. made radar systems investigated, only the 100 and 50 kW TPS-65 radar variants come close to meeting a relaxed MATCALS detection performance criteria over the specified coverage volume, but these systems are susceptible to target fall-out due to multipath interference. Georgia Tech recommends that the MATCALS ASR have a modular, solid state transmitter like that of the TPS-65 variants. Such a system would offer graceful degradation capabilities, have no need for water cooling, and might not need redundancy for FAA certification in CONUS operation. A redesign of the TPS-65 antenna, to mitigate multipath interference effects, would make that 50 kW system the choice of those evaluated.

Baseline performance specifications were established for the radar beacon system, and vendor data for U.S. manufactured equipment were evaluated. The Westinghouse antenna, Teledyne AN/APX-107 interrogators, and Sperry Univac I-SRAP I target extractor scored highest in these evaluations. A first-cut look indicates that the Discrete Address Beacon System impact on MATCALS will be a significant increase in ATC size, weight, complexity, and cost.

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SECTION 1
INTRODUCTION

1.1 HISTORICAL PERSPECTIVE

Two generic aircraft landing system concepts ("air-derived" and "ground-derived") have been employed to provide guidance under adverse weather conditions. In the air-derived system, spatially coded radio signals transmitted from a ground installation are decoded by electronic equipment aboard the aircraft to determine aircraft position relative to a prescribed approach path. In the ground-derived system, a ground-based sensor, such as a radar, tracks the aircraft and transmits flight path correction instructions to the aircraft.

The major U.S. air-derived system used by the Air Force and in civil aviation is the VHF/UHF Instrument Landing System (ILS) adopted as an international standard in 1949 by the International Civil Aviation Organization (ICAO). The ground-derived concept is embodied in various U.S. military ground-controlled approach (GCA) systems that use a precision approach radar (PAR) as the sensor element to determine aircraft position during the landing approach. The ground-derived concept is also embodied in various non-radar systems in operation or under development abroad.

Present-day landing system requirements necessitate upgraded performance capabilities, including aircraft space management, multiple aircraft control, greater reliability, improved accuracy, and all-weather landing. The VHF/UHF ILS is deficient in necessary aircraft position accuracy, data processing capability, and operational reliability. GCA systems are deficient in data processing/flow and in the precision of the radar sensor, primarily because they use dated radar technology.

Realization of these deficiencies by users prompted the Federal Aviation Administration to establish the National Plan for Development of the Microwave Landing System (MLS). The thrust of the plan was the selection of an air-derived landing system operating in the microwave region for the next generation of automatic landing systems. It was realized, however, that the full acquisition and implementation of MLS equipment at all civil and military air bases and on aircraft could take many years. In this transition period, several other on-going system developments were recognized and tolerated. Ultimately it is hoped that MLS will prevail, but development of other automatic landing systems are accepted by the National MLS plan.

The Marine Air Traffic Control and Landing System (MATCALS) is one of the military, ground-derived landing systems whose development is recognized within the plan. MATCALS is being developed by the Naval Electronic Systems Command for use at Marine, tactical, expeditionary airfields, and is designed to provide automated terminal area air traffic control and all-weather, ground-derived, landing control.

MATCALS comprises several elements which together provide all functions required for handling high density air traffic at expeditionary air bases under all-weather conditions. The functions provided include landing aircraft automatically, by instruments or by voice, providing air surveillance, and providing an operations center. The operations center interfaces with the Air Traffic Control tower, the meteorological system, and communications and data transfer equipment.

For landing control, MATCALS provides the following Navy/Marine Corps landing modes:

1. Mode I: Fully coupled automatic control to touchdown.
2. Mode IA: Fully coupled automatic control until pilot visually acquires the runway; the pilot then completes the landing.
3. Mode II: Pilot-controlled approach with guidance cues provided by cockpit displays such as a cross-pointer indicator or heads-up display, and ground-air data link by TADIL-C.
4. Expanded Mode II: Pilot-controlled approach like Mode II, but with ground-air data link provided by pseudo-ILS, voice channel link, or other communication systems which use existing communication equipment in the aircraft.
5. Mode III: Pilot-controlled approach with guidance cues provided by a ground-based operator in the classic GCA talk-down procedure.

The MATCALS is functionally organized into three system segments:

1. Air Traffic Control Subsystem (ATCS),
2. All-Weather Landing Subsystem (ALS),
3. Control and Central Subsystem (CCS).

The first and second subsystem segments listed above are the focus of technical efforts by Georgia Tech during the present contract period. The air traffic control subsystem is employed by MATCALS for a variety of purposes that fall under the general

definition of aircraft location determination. A radar beacon system component of the ATCS is the primary MATCALS sensor for providing aircraft range, bearing, and altitude data on all transponder equipped aircraft within the coverage volume. An airport surveillance radar system component is the MATCALS tertiary sensor (behind TADIL) for providing aircraft range and bearing (2D) data, independent of transponder operation. A longer range goal of MATCALS is incorporation of the Discrete Address Beacon System (DABS) now under development that will provide specific aircraft communication capability.

Past investigations examined the relative advantages of alternate Air Surveillance Radars (ASR's) that can provide the ATC function for MATCALS. Critical radar parameters include the beamwidth, scan rate, and moving target indication (MTI) technique. Areas of concern are probability of detection at maximum range, tracking accuracy, MTI performance in high ground clutter and in rain, and weather mapping.

The ALS serves as the landing control segment of MATCALS and includes a radar sensor, mini-computer, landing monitor display, and landing monitor transmitter. The radar portion of the ALS is the Precision Approach Radar (PAR), or AN/TPN-22. One function of this radar is to perform automatic landings while operating in a track-while-scan mode. This function is accomplished through use of a phase/frequency scanner antenna and real-time digital filtering algorithms implemented within the system's general purpose minicomputer.

1.2 GEORGIA TECH MATCALS TASKS

Ten distinct tasks were performed on the present contract by the MATCALS University participants: Georgia Tech, Auburn University, and Flight Transportation Associates. Four of these tasks undertaken by Georgia Tech include:

1. Update the Georgia Tech AN/TPN-22 statistical tracking error model to include rain effects, target scintillation, and antenna pattern measurements.
2. Install a TV tracker to be driven by the AN/TPN-22 tracking solution, at the NESEA test site.
3. Provide general engineering assistance to the AN/TPN-22 testing program at NESEA.

4. Perform a detailed analysis of the MATCALS Air Traffic Control (ATC) radar and beacon system requirements and determine how these needs may best be met with existing and proposed radar systems.

Task 1 represents an extension of a modeling task begun at Georgia Tech under Contract No. N00228-78C-2215 to perform a detailed statistical error analysis to determine theoretical susceptibility of the AN/TPN-22 to various sources of tracking errors. The sources of tracking errors include signal-to-noise ratio, glint, tracking filter, ground clutter, multipath interference, rain, and scintillation effects. The output of this model includes the theoretical tracking error due to each effect and the net error due to all effects. Task 1 results were summarized in the Interim Technical Report and will not be further addressed in this Final Report.

Task 2, the installation of a TV tracker, provides a range safety feature and a means of reviewing flight test performance results. TV cameras are located on the AN/TPN-22 antenna. The PAR tracking solution is indicated by a cursor superimposed on a television picture of the landing area. The results of each test run are then recorded on video tape.

Task 3 was defined as general engineering assistance to NESEA (Naval Electronic Systems Engineering Activity) at the Patuxent Naval Air Station MATCALS test site. By mutal agreement, this task was defined to be investigations of (1) multipath interference effects and (2) gated automatic gain control (GAGC) activity on the tracking performance of the TPN-22 radar. The GAGC investigation evolved into an investigation of amplitude signal processing techniques for aircraft centroid estimation.

Task 4, the air traffic control investigation, included assessments of both airport surveillance radar and radar beacon systems for MATCALS. Baseline performance specifications responsive to MATCALS requirements were established for both systems. Surveys of U.S.-made systems were performed, and data were accumulated to provide a basis for a recommended MATCALS configuration. In addition, the impact of DABS on MATCALS was investigated on a first-cut basis, and is summarized in the Interim Technical Report.

SECTION 2
TELEVISION TRACKER

2.1 INTRODUCTION

Georgia Tech is tasked by contract to define and implement a TV-Tracker for the MATCALS Test Facility. The tracker's purposes are: (1) to provide an instantaneous visual representation of the track quality of the TPN-22 radar, (2) to contribute to range safety by making possible visual observation of the test site runway from an indoor operations center, and (3) to provide an integrated record of test parameters, conditions, and results on video tape. Primary objectives to be met by the TV-Tracker are to superimpose a cursor upon a TV display of an airplane on approach, to move the cursor in response to changes in the tracking solution of the precision approach radar, and to include on the same display an alphanumeric representation of test run data.

The tracker system is operated from a CRT terminal (separate from the TV display) by entering commands via the terminal keyboard and is capable of updating the cursor position and test data display thirty times per second. Three different cursor types have been implemented. The tracker has a system tracking accuracy of $\pm$ one milliradian in azimuth and elevation. This accuracy is of the same magnitude as the specified tracking accuracy of the TPN-22 and will not distort the qualitative value of the radar error as observed on the tracker display. The system is designed to maintain target visibility from a range of four nautical miles to touchdown and to maintain stable calibration.

2.2 SYSTEM CONFIGURATION

2.2.1 OVERALL SYSTEM DESCRIPTION

Refer to Figure 2.1 for a system block diagram including all elements described in this section.

The TV-Tracker is installed in the TPN-22's computer and peripheral equipment area and is connected to the radar's UYK-20 computer via an 8-bit parallel data cable. A single camera mounted on a servo-pedestal was considered as one possible approach to implementing the tracker system but was discarded in favor of stationary cameras because of additional pedestal servo-loop errors to the radar tracking errors in the TV-Tracker display. Two cameras are used, one with a 150 mm telephoto lens for tracking

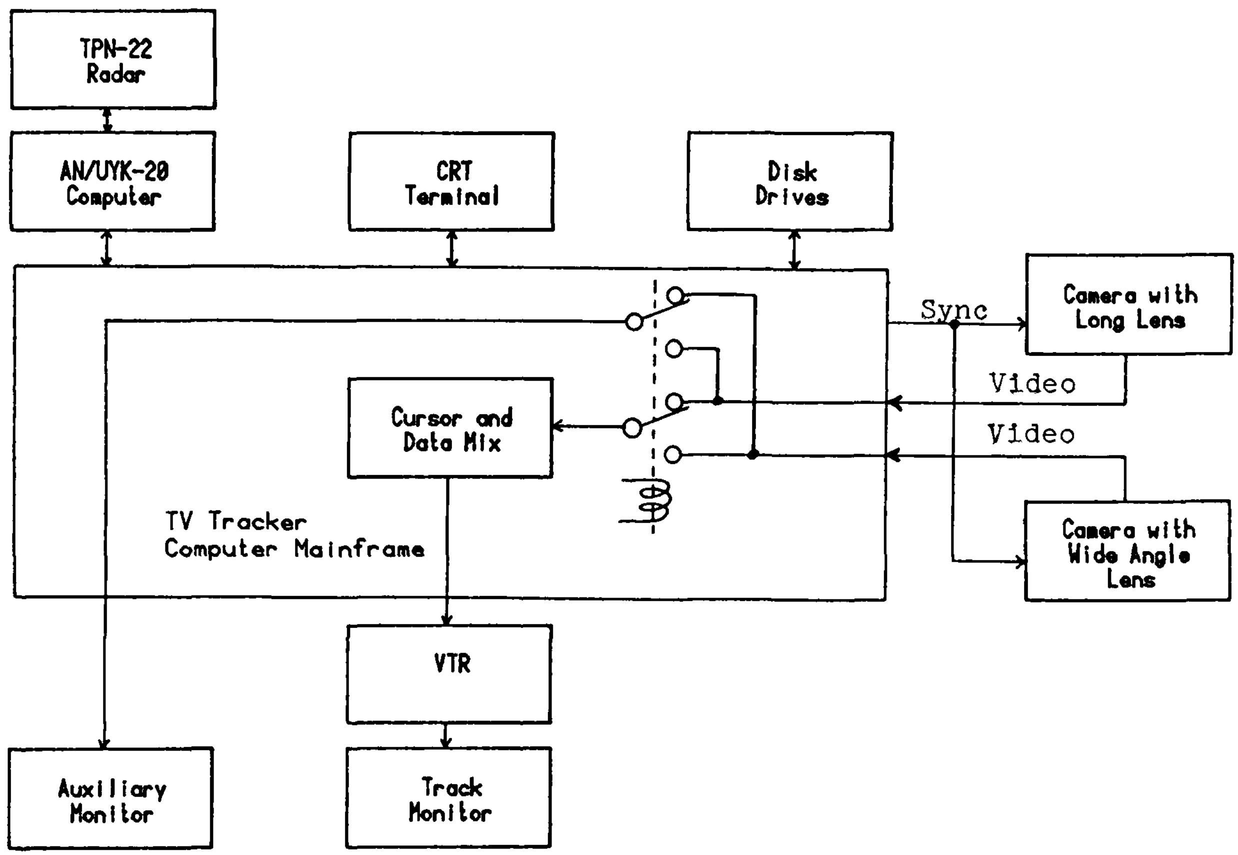

Figure 2.1. System block diagram.

at long range and another with a 50 mm wide-angle lens for tracking at near ranges to touch-down.

The camera fitted with the 150 mm lens is located on the side of the TPN-22 antenna which is farthest from the runway. The camera fitted with the 50 mm lens is located on the side of the antenna which is closest to the runway. Both cameras are rigidly attached to the antenna at a height equal to that of the antenna's vertical center line.

The image from each camera is continuously displayed on video monitors. The cursor and test data are superimposed on one of the two camera video signals that are selected by the operator, and routed through a video tape recorder before being displayed on one of the monitors. The second monitor simultaneously displays the other camera's video and does not include a cursor or alphanumeric data, but is useful to determine an optimum point during a test run at which the track function should be switched to the camera with the wide angle lens. The TV cameras, lenses, video monitors, video tape recorder, and interconnecting power, and signal cables are all government furnished equipment. Georgia Tech supplied the TV Tracker computer, CRT terminal, floppy disk drives, hardware interface to the UYK-20, and a software user system that gives prompt messages to the operator describing each step in calibration or track procedure.

2.2.2. HARDWARE DESCRIPTION

The hardware selected to implement the TV-Tracker is centered around the "CAT-100" graphics and imaging system manufactured by Digital Video Research. The CAT-100 is built on two printed circuit boards that conform to the IEEE 696.1/02, S-100 microcomputer bus standard.

This graphics system was selected to produce the track display for four reasons: (1) it provides sufficient graphics pixel resolution to implement the required tracking accuracy (576 pixels spanning a 14 degree field of view yields a 0.42 mrad resolution); (2) it is software reconfigurable; (3) it has an on-board video mixer to superimpose the graphics data onto camera video; and (4) it offers an image enhancing feature called "contouring." This last feature sends the camera video signal through a window comparator and mixes a black (or white if desired) video level onto the signal during the portions of the signal that fall within the window. By adjusting the two thresholds with potentiometers mounted on the back of the computer, a black (or white) 'contour' around images in the display can be formed to enhance the detectability of the target in varying light and weather conditions.

Selection of the CAT-100 implied two fundamental requirements for the remainder of the system hardware: (1) a computer was necessary to drive the CAT-100 and (2) the computer had to conform to the IEE 696.1/02, S-100 microcomputer bus standard so that it could be used and reside with the memory and input/output elements in the same system chassis.

The Intel 8080 and the Zilog Z-80 were the only computers available on an S-100 format printed circuit board. The Z-80 was chosen for its expanded instruction set and high clock speed (4 MHz). The specific choice was an Ithaca Audio Systems Z-80 CPU and S-100 motherboard (bus) with ten extra card slots and power supply. Two 16K static random access memory (RAM) cards were chosen from Seattle Computer Products. A Cromemco dual parallel and dual serial port, Input/Output board was chosen to interface the computer with the CRT terminal, the UYK-20, and a printer during software development. A Thinker Toys "Disc Jockey" disk controller card and two Morrow "Discus" 8 inch floppy disk drives were added for non-volatile program and data storage. For program development and for operator control, a Perkin Elmer "Bantam" 950 intelligent CRT terminal was chosen for its flexible interface and cursor addressing capabilities.

2.2.3 SOFTWARE DESCRIPTION

The tracker software is intended to be a stand alone user system which enables an operator with only a general understanding of the basic tracking function to calibrate and operate the TV-tracker. The software is also intended to be field serviceable without major modifications to structure. The stand alone nature of the software is ensured by extensive prompting at each step during the calibration and track modes. The field servicability is enhanced by an I/O module, that handles communication with the UYK-20 computer. Adjustments to software required by changes to installation of the TV Tracker-UYK-20 interface can be made in this module of source code, reassembled, and overlaid into the main body of software without changing the overall structure or reassembling the entire software package.

The top level of software organization is illustrated in Figure 2.2, and the user system executive is illustrated in Figure 2.3. After bootstrapping, the TV-Tracker system comes up in the user system executive and displays a system menu. From this menu, the user may control contouring, cursor, and camera selection, set the real time clock, execute utilities, or enter the On-Line/Track mode.

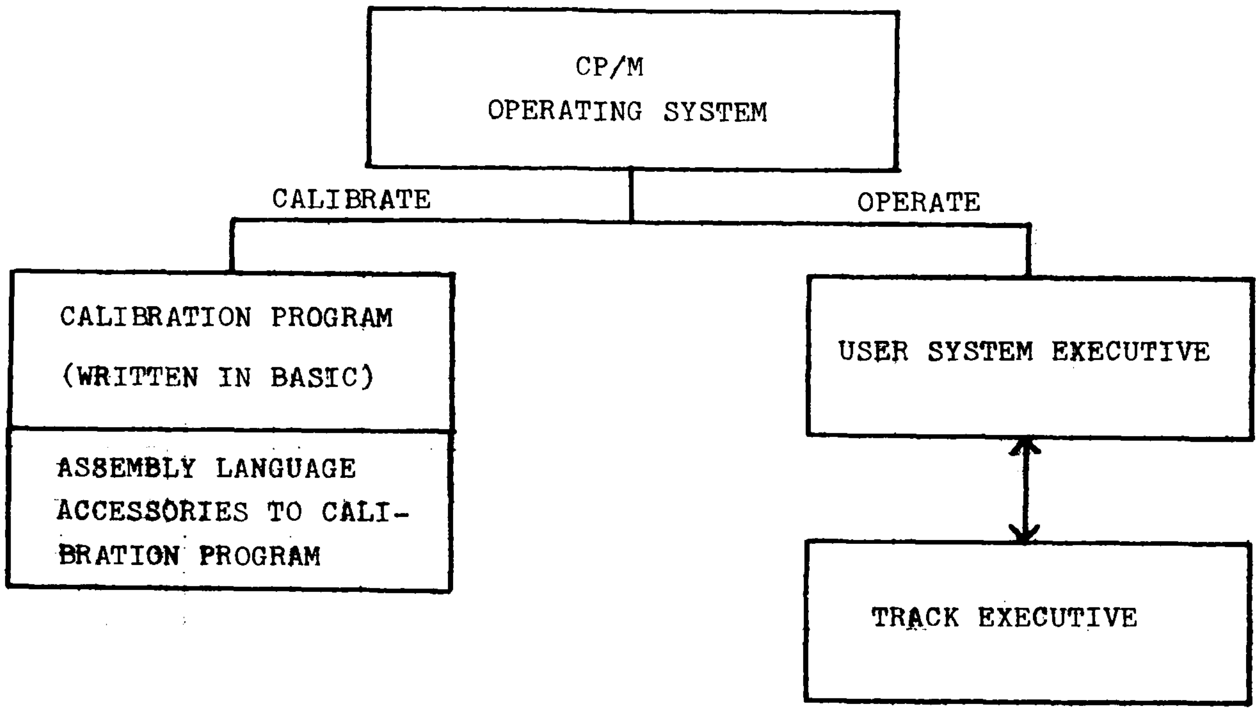

Figure 2.2. Top level software organization.

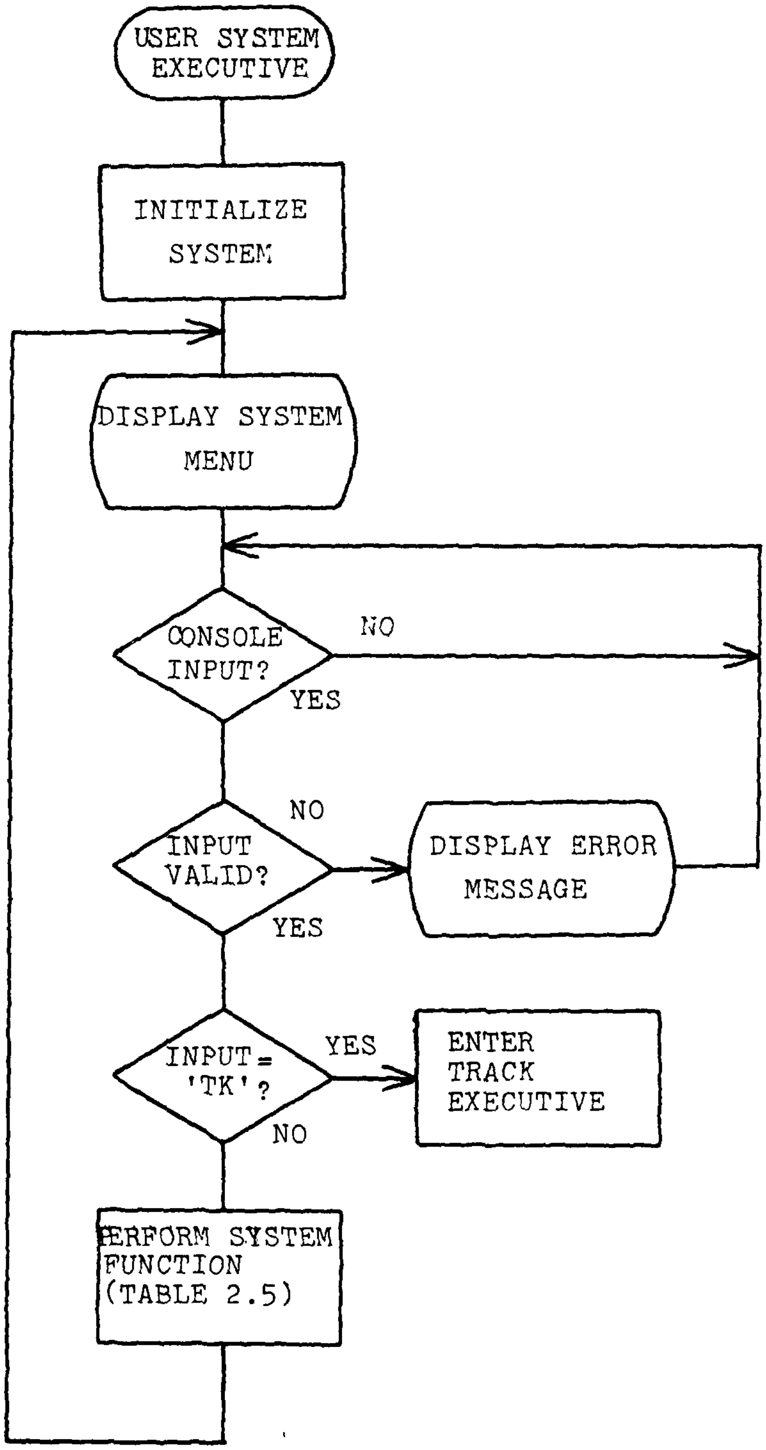

Figure 2.3. User system executive.

The On-Line/Track mode polls the latched Tracker - UYK-20 interface control line "External Function Acknowledge" and executes the I/O and track functions if the latched input is true, otherwise it polls the keyboard for the occurence of On-Line commands such as: (1) display track menu, (2) select wide or long lens (3) turn on or off the contouring feature, (4) toggle lens selection, (5) toggle polarity of contouring (white/black), (6) trace I/O. These functions and control processes are illustrated in Figure 2.4.

2.2.4 INTERFACE DESCRIPTION

2.2.4.1 General

The 8-bit parallel interface between the AN/UYK-20 Precision Approach Radar (PAR) computer and the TV-Tracker is accomplished by one cable containing 11 twisted pair wires which connect the UYK-20'S input/output channel number six through a hardware interface board to the TV-Tracker's parallel input/output channel A. The electrical characteristics of the UYK-20 interface conform to the NTDS -15 V specification. The Tracker interface is standard Transistor - Transistor Logic (TTL). Figure 2.5 illustrates the interface signals and terminology.

2.2.4.2 AN/UYK-20 Electrical Interface

Complete electrical specifications for the UYK-20 interface are given in the publication "Military Computers, I/0 description" by Sperry Univac Defense Systems, St. Paul Minnesota, hereafter referred to as the "Sperry I/0 Manual."

2.2.4.3 TV-Tracker Electrical Interface

Functional specifications for the TV-Tracker interface are the same as those for the UYK-20 interface described in Section 2.2.4.2, except for the open circuit logic definition. In the TV-Tracker interface, input circuits are such that the effect will be as though a "one" were present at the input if an input wire is disconnected. All data and control signals are Transistor-Transistor Logic (TTL) levels and are transmitted over a twelve inch ribbon cable within the TV-Tracker computer mainframe.

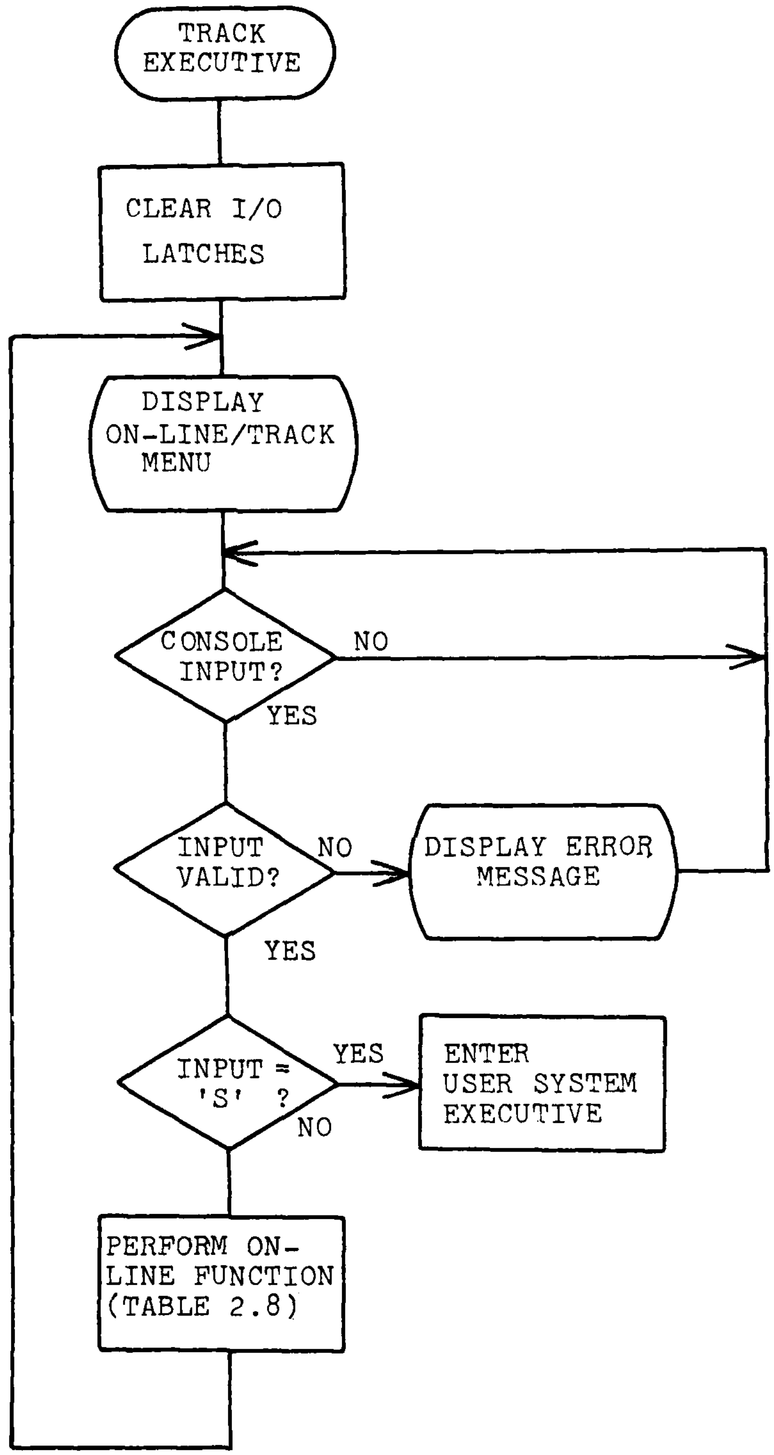

Figure 2.4. Track executive.

2.2.4.4 Physical Interface

Timing constraints of the NTDS interface are met, and translation to the TTL levels required by the TV-Tracker are accomplished by a hardware interface board which is resident inside the TV-Tracker computer main frame. Signals from the UYK-20 arrive at an SPO6E-22-55 SR connector on the back of the tracker computer. A wire list for this connector is shown in Table 2.1. These inputs are internally connected to the hardware interface board. Data and control signals are transmitted over a twelve inch ribbon cable to the microcomputers input/output board. (Figure 2.5).

2.2.4.5 Interface Message Format

The data transferred, description of each byte, and scaling of values are described in Table 2.2.

2.2.4.6. Data Transfer Protocol

The UYK-20 uses two different output modes to communicate each update message to the TV-Tracker. The Tracker first receives an 8-bit external function code (69 H) via the UYK-20's "Forced External Function" method. Following receipt of a valid External Function Code, 26 data words are sent to the Tracker via the UYK-20'S "Computer to Peripheral" output data transfer method. Protocol for these I/O methods is fully documented in the Sperry I/O manual.

If an update is sent to the TV-Tracker before it has completed processing the last update, the Tracker will continue to process the current data until the track cycle is completed. If another update has occurred during the last update cycle, the EFA (External Function Acknowledge) latch will be set. The Tracker polls this latch and displays "Data Update Missed" to notify the operator that an update was missed. The latch is then cleared, and the tracker awaits the next forced external function output from the UYK-20.

2.3 HARDWARE CONFIGURATION

2.3.1 INTERCONNECTIONS

The following interconnections are necessary to operate the TV-Tracker (video and synchronization connections require 75 ohm coaxial cable with BNC connectors):

1. The red 50 wire flat cable extending from the back of the computer should be connected to the 50 pin jack on the back of the disk drive unit at the far left. IMPORTANT - one edge of the cable has an ORANGE TRACE wire. This side of the cable should be UP.

TABLE 2.1. AN/UYK-20 TO TV-TRACKER WIRE LIST

Signal Name	TPN-22 End MS3112E20-41 P	TV-Tracker End SP06E-22-55 (SR)
Data Bit 00	A	A
RNT	B	B
Data Bit 01	C	C
RTN	D	D
Data Bit 02	E	E
RTN	F	F
Data Bit 03	G	G
RTN	H	H
Data Bit 04	J	J
RTN	K	K
Data Bit 05	L	L
RTN	M	M
Data Bit 06	N	N
RTN	P	P
Data Bit 07	R	R
RTN	S	S
ODA	j	j
RTN	k	k
EFA	p	p
RTN	q	q
ODR	m	m
RTN	n	n
Ground	Open Loop	

Table 2.2
Message Format (Byte Transfer Mode) from
AN/UYK-20 to TV-Tracker

Word Number (Octal)	Content
0	EXT. FUNC. CODE
1	VPIX WORD 1
2	VPIX WORD 2
3	HPIX WORD 1
4	HPIX WORD 2
5	CAMERA
6	Spare
7	Spare
10	Spare
11	Spare
12	DS TKNO
13	Spare
14	CQUAL
15	Spare
.	.
.	.
.	.
26	Spare
27	CTIME WORD 1
30	CTIME WORD 2
31	CTIME WORD 3
32	CTIME WORD 4

WORD FORMATS
ENTERNAL FUNCTION CODE (WORD 0) = 69 H
VERTICAL DISPLAY ADDRESS (WORDS 1_8,2_8)
MSB = BIT #7 OF WORD 1_8
LSB = BIT #0 OF WORD 2_8

HOROZONTAL DISPLAY ADDRESS (WORD 3_8 OF 4_8)
MSB = BIT #7 OF WORD 3_8
LSB = BIT #0 OF WORD 4_8

CAMERA SELECTION (WORD 5_8)
ØFF H = SELECT LONG LENS
ØØH = SELECT WIDE LENS

DATA SOURCE (WORD 12_8)
(DS)
MSB = BIT #7 OF WORD 12_8
LSB = BIT #6 OF WORD 12_8

MSB	LSB	
0	0	- FILTERED MODE 1 TARGET DATA
0	1	- FILTERED MODE 2 TARGET DATA
1	0	LOG-COMPRESSED TARGET DATA
1	1	PRE-COMPRESSED TARGET DATA

TRACK NUMBER (WORD 12_8)
(TK NO)
MSB = BIT #2 OR WORD 12_8
LSB = BIT #0 OF WORD 12_8

MSB		LSB	
0	0	1	TRACK NO 1
1	1	0	TRACK NO 6

TRACK QUALITY (WORD 14_8)
(CQUAL)
MSB = BIT #1 OF WORD 14_8
LSB = BIT #0 OF WORD 14_8

MSB	LSB	
0	0	TRACK TERMINATED
0	1	MISS
1	0	PARTIAL HIT
1	1	HIT

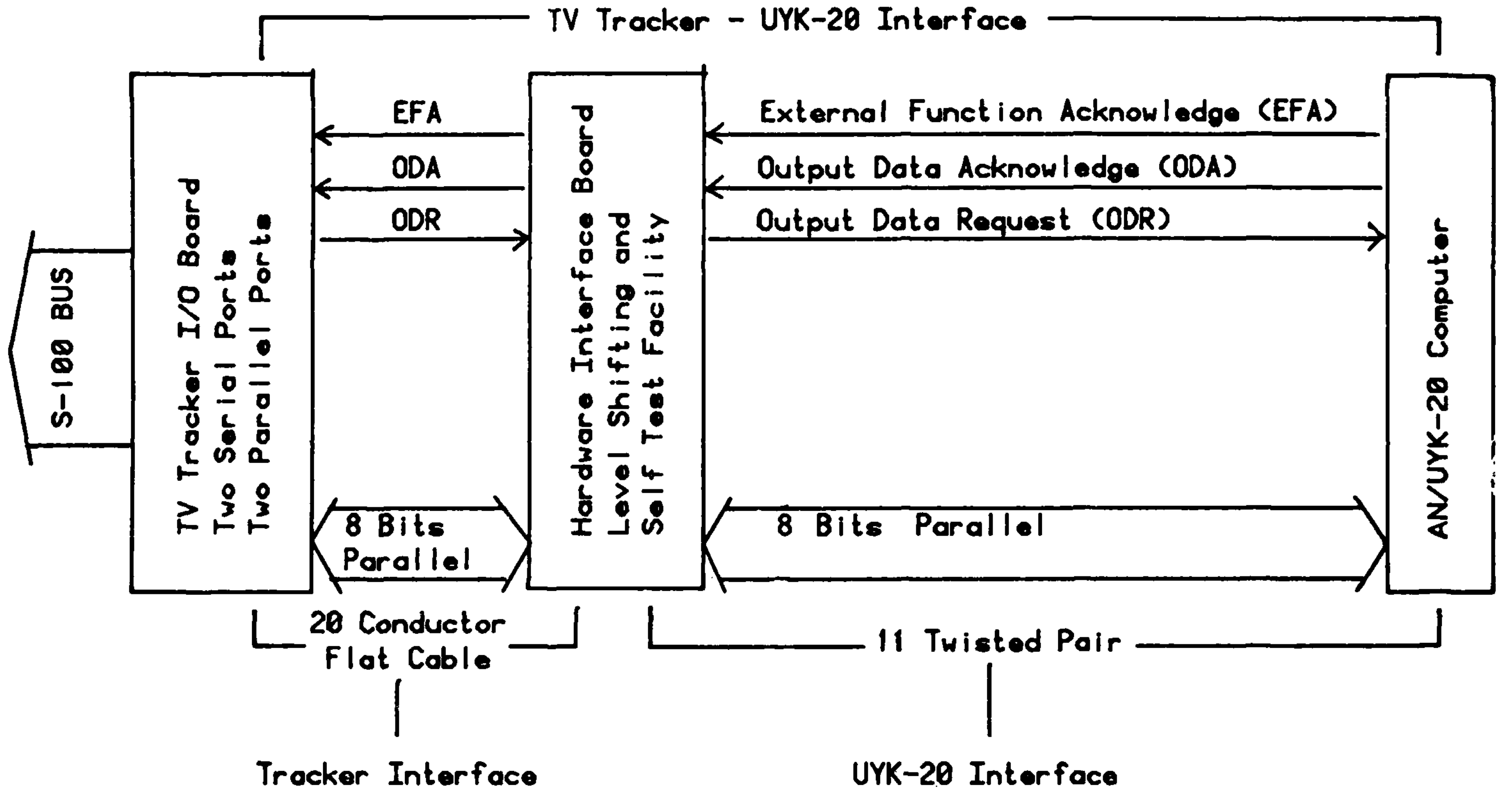

Figure 2.5. Interface signals and terminology.

2. The serial data cable extending from the back of the CRT console should be connected to the jack on the back of the computer marked "CONSOLE". The four mode selection switches on the console keyboard should be set as shown in Table 2.3.

Table 2.3. CRT Console Mode Switch Settings

Switch Label	Switch Position
NUM ONLY	up
U/C	down
PRINT	up
LINE	down

3. Line voltage should be supplied to the CRT Console, the computer, and the disk drive unit.
4. Horizontal and vertical synchronization signals are generated in the computer mainframe and are available as composite sync on the rear panel at the BNC connector marked 'CSYNC'. This output should be connected to the external sync inputs of both cameras and both cameras should be set for external synchronization.
5. The composite video output from the camera with the wide angle lens should be connected to the computer input marked 'CAMERA 1'. The composite video output from the camera with the long lens should be connected to the computer input marked 'CAMERA 2'.
6. The computer output marked 'TRK/VTR MON' should be connected to the input of the video tape recorder, (VTR) if one is used, or to the input of one video monitor designated as the 'track' monitor if a VTR is not included. If a VTR is used, a composite video output from the VTR should be connected to drive the 'track' monitor.
7. The computer output marked 'AUX MON' should be connected to drive another video monitor designated as the 'auxiliary' monitor. Both monitors should be set to use internal synchronization derived from the composite video input.
8. Connect the data cable from the UYK-20 computer to the connector on the back of the TV-Tracker computer marked 'UYK-20 INPUT'

2.3.2 AN/UYK-20 TO TV-TRACKER HARDWARE INTERFACE

The AN/UYK-20 to TV-Tracker hardware interface is built on an S-100 bus compatible circuit board that translates logic levels between the two computers and provides a self test facility for the TV-Tracker. A schematic diagram of the board is included in Appendix A. NTDS logic '0' and logic '1' levels arriving at the TV-Tracker from the UYK-20 computer correspond to a nominal -15 and zero volts, respectively. NTDS receiver circuits U1 and U2 translate these logic levels into Transistor-Transistor Logic levels for use in the TV-Tracker computer. NTDS driver circuit U3 translates the TV-Tracker's one output from TTL levels to the NTDS logic levels and transmits it to the UYK-20 computer.

The interface self test facility is not used during normal calibration or operating procedures, but is provided for use as a troubleshooting aid during installation of the TV-Tracker. The TV-Tracker can be taken off-line using this facility, and all interface signals can be generated locally.

2.3.3 TURN ON PROCEDURE

The following three step process brings the assembled and installed TV-Tracker system to its operational state (under console control).

1. Turn all AC line switches to the 'ON' position. The line switch for the TV-Tracker computer is the alarm type key switch on the front panel. The line switch for the disk drives is on the back panel. For the CRT console, the switch is on the front panel under the glare shield extrusion which surrounds the screen. Verify that primary power is turned on to the TV cameras, the video monitors, and the VTR.
2. Open the LEFT disk drive (if not already open) by pressing the rectangular button immediately below the slot cover. Grasping the TV-Tracker System Software Disk by the edge closest to the label and with the label facing up, insert the disk into the LEFT disk drive labeled 'A.' Close the slot cover by pushing down until it snaps.
3. Bootstrap the system by toggling the computer front panel switch marked 'RESET/EXT CLR' up to the RESET position and release Toggle the computer front panel switch labled 'RUN/STOP' up to the RUN position and release. The console will display the prompt 'A >>' indicating that the computer is under console control.

2.4 SOFTWARE

2.4.1 PRIMARY OPERATING SYSTEM

The TV-Tracker computer runs under the primary operating system 'CP/M' (a registered trademark of Digital Research, Inc.) which stands for 'Control Program for Microprocessors.' Full documentation of this operating system (Version 1.4) is available from Digital Research, P.O. Box 579, Pacific Grove, California 93950. This primary operating system is transparent to the user, and no knowledge of its commands or facilities is required for full operation of the TV-Tracker beyond what is included herein.

2.4.2 USER OPERATING SYSTEM

The User Operating System software developed for the TV-Tracker by Georgia Tech requires no programming skills on the part of the user. However, a few instructions on running the software are necessary.

2.4.2.1 Bootstrap Loading

Booting the system loads CP/M from disk into memory and gives control to CP/M's monitor program, called the Console Command Processor (CCP). The procedure for booting the system is described in Section 2.3.3, step 3.

2.4.2.2 Loading the TV-Tracker Program

The console will display the CCP prompt:

A>>

after bootstrapping. Type 'TRACKER' after the prompt followed by the RETURN key (CR) as shown:

A>> TRACKER (CR)

The CCP will then load the TV-Tracker program into memory, release control to the program, and the program will display the User System prompt:

PRESS RETURN FOR MENU***

2.4.2.3 Correcting Keyboard Entry Mistakes

Keyboard entry errors are handled differently depending on (1) which program is controlling the keyboard and (2) the nature of the mistake. The net effect is to free the user from concern for error handling once program control has passed to the User System Executive because mistakes are handled straightforwardly if not automatically. Table 2.4 summarizes possible cases.

Table 2.4. Error Recovery Procedures

Command/Input System Activity	Controlling Program	Error Handling
Loading Program	CCP	Type CTRL U and retype 'TRACKER' (cr)
Invalid Two Letter Menu Command Entered	User System Executive	'IMPROPER ENTRY. TRY AGAIN.' is displayed and control is returned to the menu automatically.
Valid But Incorrect Menu Command Entered	User System Executive	Command entered will be executed Executive Control passed automatically back to the menu or, if the incorrectly executed function stops for an input, typing 'M' (Menu request) will pass control to the menu.

2.4.3 THE USER SYSTEM MENU

The central control point for all TV-Tracker operating software is the User System Menu. The occurrence of this control point is marked by the prompt:

PRESS RETURN FOR MENU ***

When this prompt appears between functions during operation of the TV-Tracker, the following menu of options may be displayed by pressing CR:

MENU

TK-TRACK	PC-PROCESS CURRENT BUFFER
ST-SET REAL TIME CLOCK	MC-MOVE CURSOR
WL-SET WIDE LENS	LL-SET LONG LENS
WB-WHITE/BLACK GRAPHICS	SC-SELECT CURSOR TYPE

The user will soon have memorized the most often used two letter commands of the menu, however, and redisplaying the menu may be unnecessary. Commands may be entered directly after the prompt without going to the menu. Table 2.5 lists brief descriptions of the functions performed in response to each of these commands. The calibration procedure and terminology is discussed in more detail in Section 2.4.

2.4.4 CALIBRATION

2.4.4.1 General

The purpose of calibration is to make tracking a function of (1) the exact camera alignment (from which the physical location of a single point on the display is derived) and (2) the exact power of the camera lenses (from which the scale of the display is derived). From this location and scale, any other point within the display may be determined, by placing the track cursor over one calibration target, the location of which is precisely known (calibration targets and their locations are discussed in Section 2.4.4.3), noting its horizontal and vertical pixel address (Hpix and Vpix, respectively) on the display, and repeating the process for another calibration target. In the horizontal plane, this information is used to compute a slope (scale) and constant (location) for a linear mapping of target Azimuth and Elevation into Hpix and Vpix coordinates. In the vertical plane, location is determined from the aforementioned data. Vertical scale is inferred from the previously computed horizontal scale and the aspect ratios of the graphics address space and the TV display as shown below:

$$\text{Vertical Scale} = \text{Horizontal Scale (previously computed)} \times K,$$

where

$$K = \left(\frac{\text{Total Number of Vertical Lines}}{\text{Total Number of Horizontal Pixels}}\right) \div \left(\begin{array}{c}\text{TV Display}\\ \text{Aspect Ratio}\end{array}\right)$$

$$= \left(\frac{480}{576}\right) \div \left(\frac{3}{4}\right) = 1.1111$$

2.4.4.2 Gross Alignment of Cameras

Gross alignment of the TV cameras is required prior to system calibration. This alignment procedure involves adjusting the camera mount angles while watching the video monitors. For the camera fitted with the wide angle lens, the mount should be adjusted until calibration target numbers 2 and 3 (Figure 2.6) are visible in the video

Table 2.5
List of User System Menu Functions

Command	Functions Performed in Response to the Command
'TK'	TK displays a menu of possible 'in track' commands and enters the on-line or 'track' mode. The track is discussed in more detail in Section 3.5.
'PC'	PC (Process Current buffer) reads data from the I10 buffer allocated for messages from the UYK-20 computer, processes that data in the same way as if it had been read during the 'track' mode, and returns to the menu.
'ST'	ST (Set Time) prompts the user to enter a reference time from 00:00 to 23:59 hours. The displayed time is always computed from this reference and the real time clock (CTIME). The reference must be reset after each power down/power up cycle of the TV-Tracker and must be done while receiving valid 'CTIME' data from the UYK-20.
'MC'	MC (Move Cursor) enables the user to move the cursor around the display in response to keyboard commands which are explained in prompt messages to the console. This is a system utility which is not required for normal operation or calibration.
'WL'	WL (Wide Lens) selects video from the camera fitted with the wide angle lens for display with the cursor and test run data in the track monitor. Simultaneously, video from the other camera is routed to the auxillary monitor.
'LL'	LL (Long Lens) selects video from the camera fitted with the high power lens for display with the cursor and test run data in the track monitor. Simultaneously, video from the other camera is routed to the auxillary monitor.
'WB'	WB (White/Black) toggles the display function between white graphics on a dark background and black graphics on a light background.

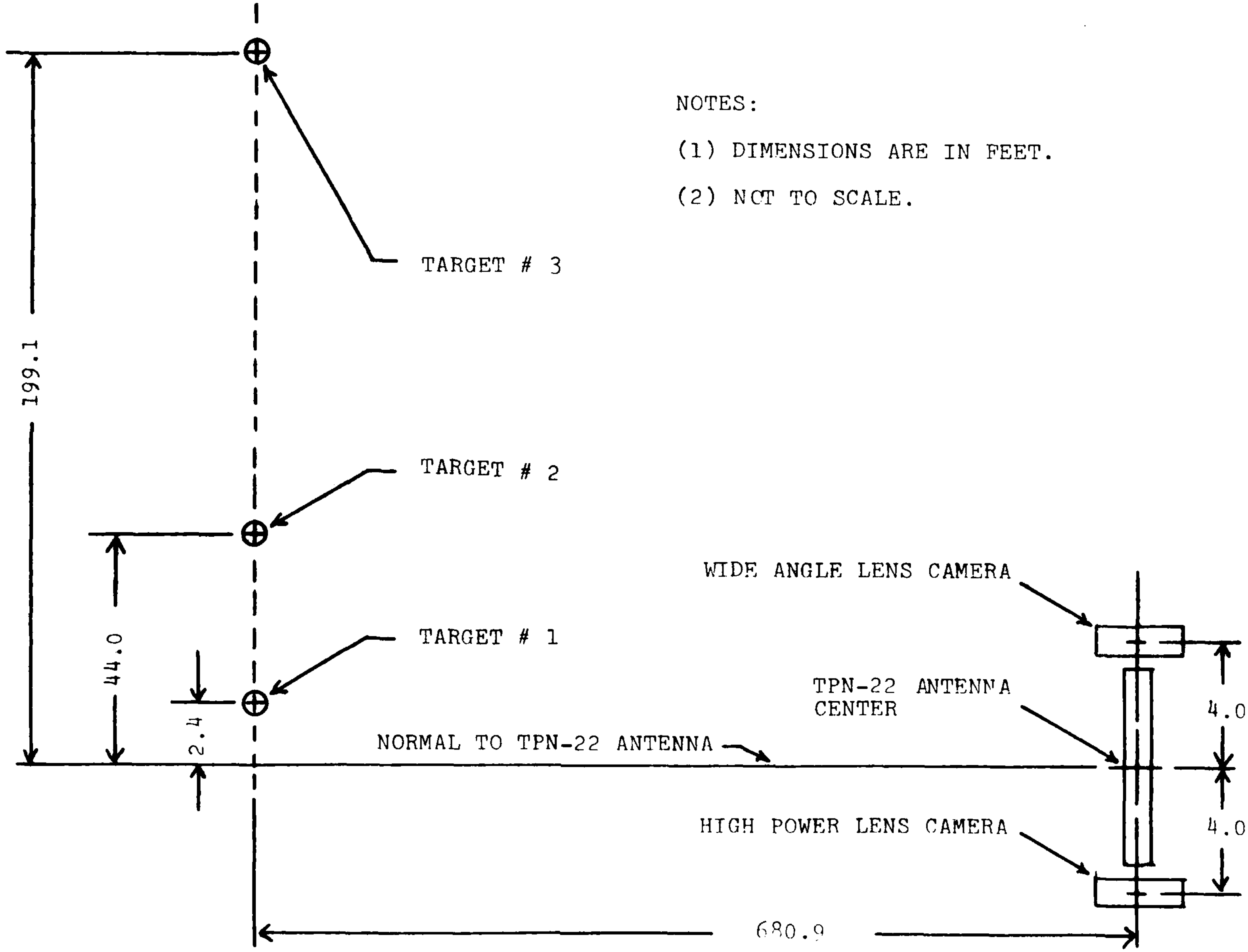

Figure 2.6. Calibration target designation.

monitor approximately one inch from the bottom of the display. Similarly, for the camera fitted with the long lens, its mount should be adjusted until calibration target numbers 1 and 2 (Figure 2.6) are visible in the video monitor approximately one half inch from the bottom of the display. This procedure accomplishes sufficient alignment of the camera line of sight, although rotation of the camera's horizontal scan around the line of sight may yet vary from parallel to the TPN-22 antenna's horizontal plane as required for system operation. This difference may be as large as 1.6 degrees, however, before its effect on calibration accuracy exceeds display resolution. If this difference is suspected to be larger than 1.6 degrees, execution of the calibration procedure (including rotational alignment as described in Section 2.4.4.4) twice in succession will force the error to converge within system specifications.

2.4.4.3 Theory of Calibration

The objective of the calibration procedure is to precisely locate each respective camera's field of view within a coordinate system referenced to that camera. Target position data in rectangular coordinates with respect to the touchdown point, as designated by the UYK-20 computer, can be translated by known offsets into coordinates with respect to the cameras, transformed into polar azimuth and elevation angle coordinates, and mapped into the field of view of a selected camera for display.

The polar and rectangular coordinate systems used in this discussion are shown together in Figure 2.7 and are located (with the origin at the camera location unless otherwise specified) as shown in Figures 2.8 and 2.9.

Azimuth and elevation (AZ and EL) coordinates derived from the relationships illustrated in Figure 2.7 are mapped into graphics display coordinates Hpix and Vpix as shown in Figures 2.8 amd 2.9. Because the origin for the display is the upper left hand corner and the polar coordinates are derived from a right handed rectangular basis (Figure 2.10), INCREASING values of Hpix and Vpix correspond to DECREASING values of AZ and EL. The scale factors or slopes of the corresponding linear maps will therefore be negative.

Placement of calibration targets is motivated by system hardware and test site visibility requirements. The TV-Tracker's graphics system is capable of angle resolutions from 0.13 to 0.42 milliradians depending on which of the two camera lenses is used and the applicable polar coordinate, as shown in Table 2.6.

$AZ = \mathrm{Arctan}\ (Y/X)$
$EL = \mathrm{Arcsin}\ (Z/R)$

$R = X + Y + Z$

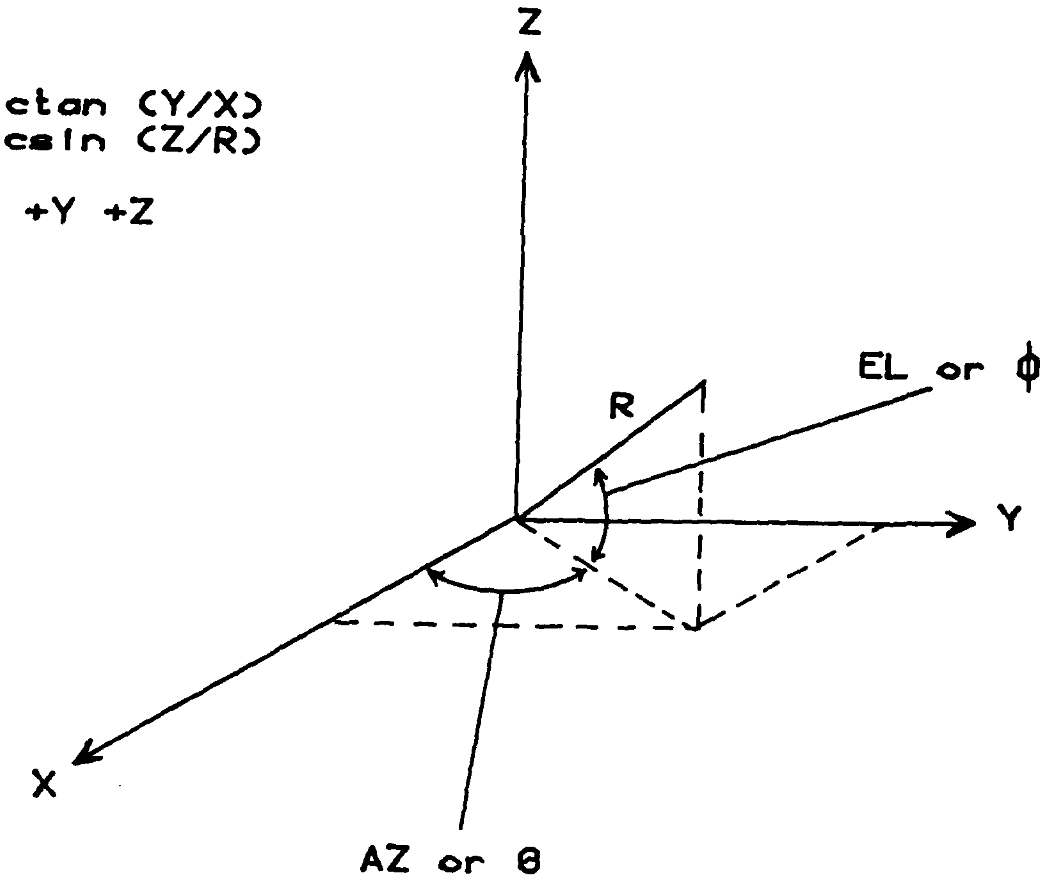

Figure 2.7. Coordinate systems and transformation.

NOTES:

(1) ANGLES DELIMITING EACH CAMERA'S FIELD OF VIEW ARE GIVEN WITH REFERENCE TO A LINE WHICH IS PARALLEL TO THE TPN-22'S 'BEAM NORMAL' AND WHICH PASSES THROUGH THE ASSOCIATED CAMERA.

(2) NOT TO SCALE.

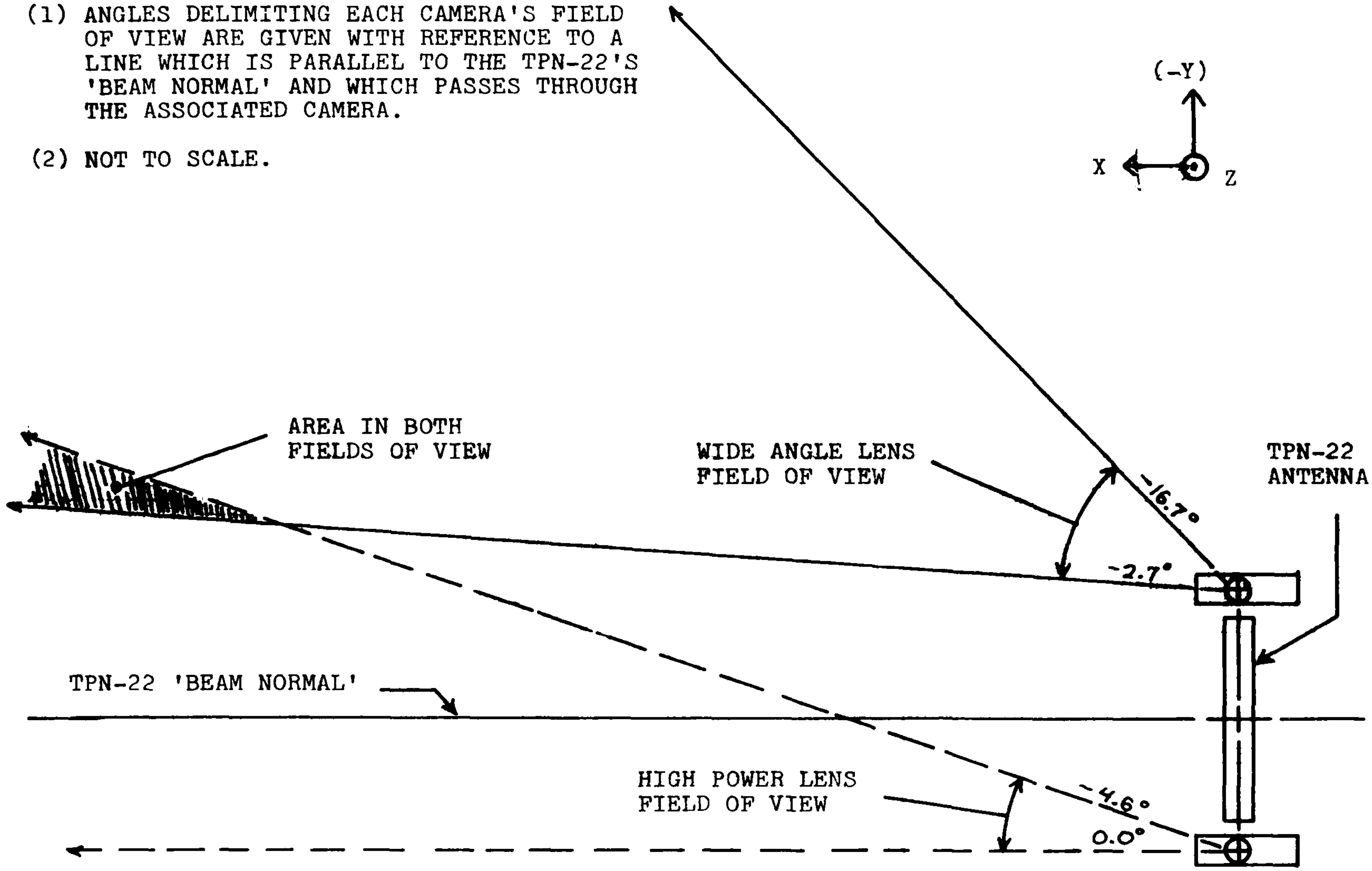

Figure 2.8. Aerial schematic of test site.

NOTES:

(1) ANGLES DELIMITING EACH CAMERA'S FIELD OF VIEW ARE GIVEN WITH REFERENCE TO A LINE WHICH IS PARALLEL TO THE GROUND AND WHICH PASSES THROUGH THE ASSOCIATED CAMERA.

(2) NOT TO SCALE.

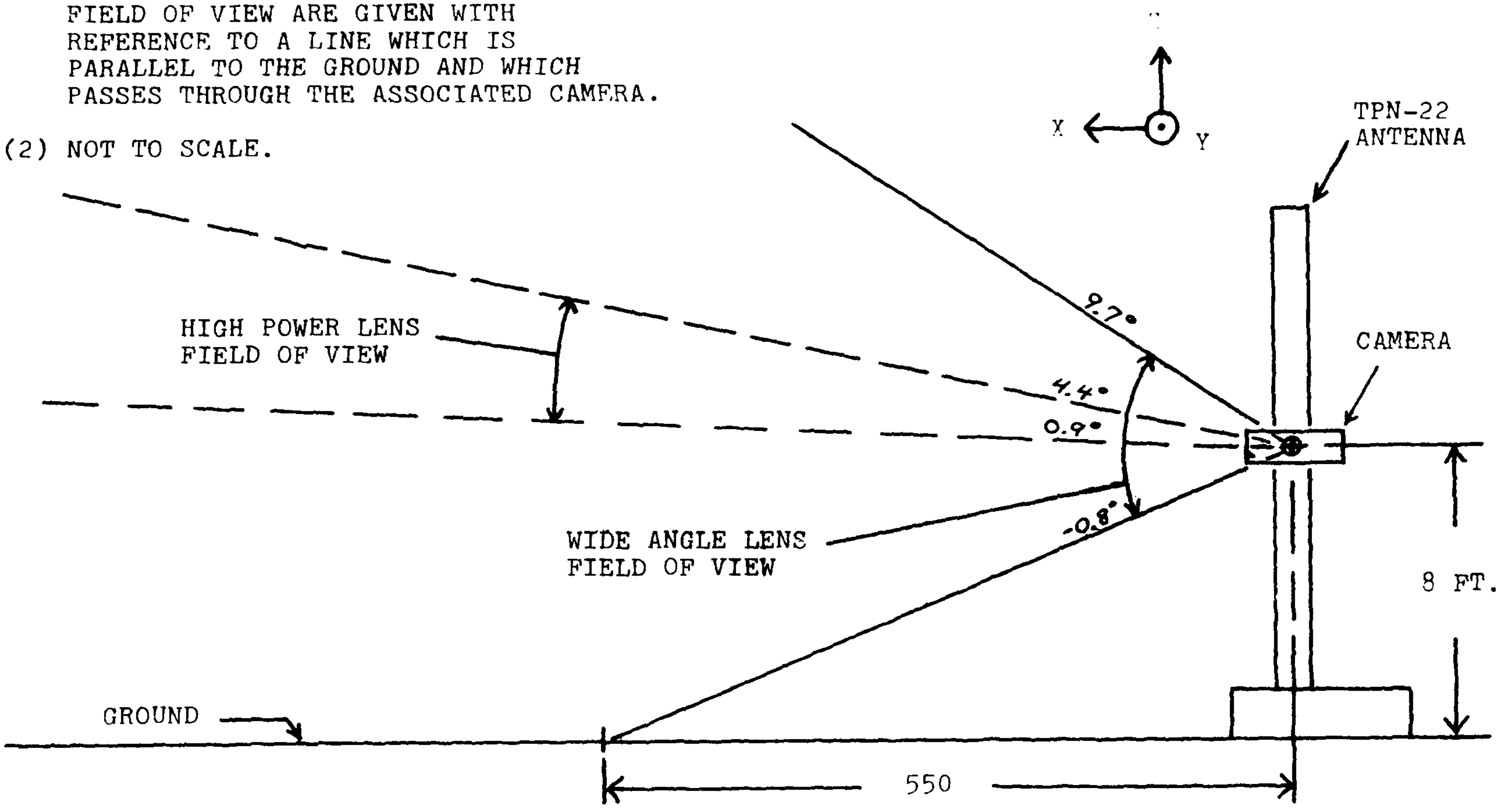

Figure 2.9. Elevation schematic of test site.

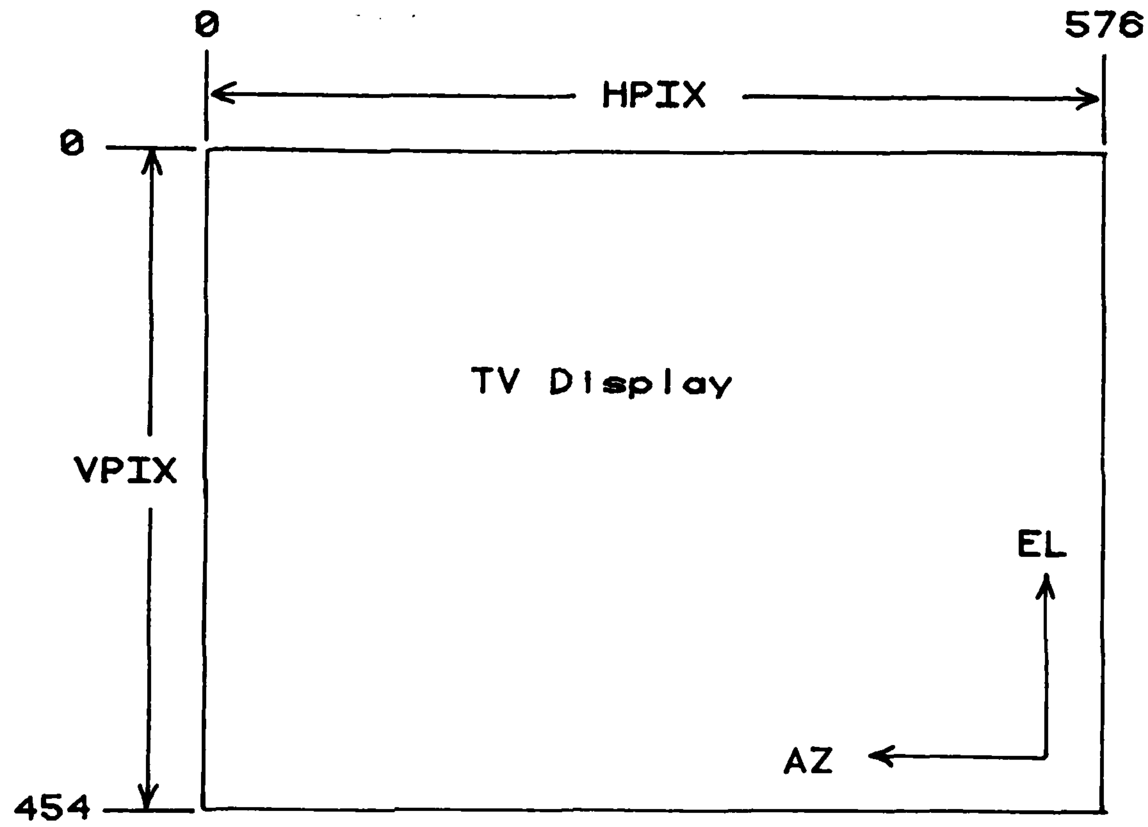

Figure 2.10. Mapping of AZ and EL into display pixel coordinates HPIX and VPIX.

Table 2.6. Graphics System Resolution

Polar Coordinate	Long Lens Unit Angle/Pixel	Wide Angle Lens (Unit Angle/Pixel)
Elevation	0.00013 rad	0.00038 rad
	0.00729 deg	0.02138 deg
Azimuth	0.00014 rad	0.00042 rad
	0.00799 deg	0.02431 deg

Calibration of the system to an accuracy equal to the best of these resolution capabilities poses some considerable logistical problems of precise target placement at long ranges and of significant target heights. Because these resolutions are significantly better than the system accuracy specification of ± 1 milliradian, these problems may be avoided by adopting a calibration standard closer to the system specification. A calibration accuracy of $\pm$ 0.21 milliradians corresponds to one half the minimum resolvable azimuth angle for the wide angle lens and is chosen as a calibration standard of accuracy.

Range to the calibration targets should be made large enough so that a specified maximum error in target placement causes a difference in line of sight angle which is less than the calibration standard of accuracy. For purposes of this discussion, the maximum error in target placement shall be ± 3 inches in any direction. It follows, then that the minimum range from the cameras to any calibration target shall be 677 feet.

Location of the calibration targets also depends upon what areas of the test site are to be within the cameras' fields of view. The primary elevation angles of interest are those between two and four degrees, corresponding to the possible aircraft glide slopes. The setting of the wide angle lens' elevation field of view is chosen to allow observation of the aircraft at runway level for any probable touchdown range (600 ft. minimum) and to extend higher than the maximum glideslope allowing visibility to touchdown range during 'flyovers' of altitudes up to 100 feet. Field of view boundaries for this setting are shown in Figure 2.9. The elevation setting for the long lens field of view is also illustrated in Figure 2.9 and is chosen to center more closely around probable glideslopes for tracking at long range. The azimuth angle from the cameras to the target changes

during the course of a test run from a very small angle to a maximum of approximately -17 degrees. The right hand boundary of the wide angle lens, horizontal field of view is set to include this maximum look angle. The left boundary of the long lens, horizontal field of view is set to 0 degrees in order to ensure line of sight visibility at maximum range. These fields of view are illustrated in Figure 2.8. The 'hand off' interval, for some part of which (depending on glideslope) the target will be visible in both cameras, is clarified by Figure 2.11. If the calibration target locations are chosen to delimit the center 75% to 90% of the desired horizontal fields of view, the calibration process will be sufficiently insensitive to gross alignment errors while maintaining calibration accuracy.

A recommended set of surveyed calibration target locations, consistant with all the aforementioned system and site considerations, is summarized in Table 2.7. The coordinates of these locations are given with reference to the center of the TPN-22 antenna. Stands for calibration targets must extend 15 feet higher than the camera in order to position the targets appropriately in the fields of view. Stands may be constructed of appropriate lengths of 3 inch diameter rigid black PVC pipe, held upright by any convenient and stable means. A plumb bob arrangement may be employed to verify that the target is directly over the surveyed position marker as illustrated in Figure 2.12. The actual targets for the TV-Tracker calibration may be 8 inch diameter disks attached to the top of the target stands and painted with a 4 inch diameter white dot in the center, surrounded by a two inch wide black perimeter.

2.4.4.4 Calibration Procedure

Initial calibration of the TV-Tracker is accomplished in three steps: (1) camera rotational alignment, (2) system calibration for the wide angle lens, and (3) system calibration for the long lens. The order of steps (2) and (3) is completely arbitrary, and the respective procedures are identical. To execute the calibration program, type "CRUN2 CAL" after the CCP prompt "A>>". The following menu will be displayed.

MATCALS TV TRACKER CALIBRATION PROGRAM

ENTER NUMBER FOR DESIRED OPERATION

(1) INITIALIZE AND CLEAR SCREEN

(2) MOVE CURSOR AROUND SCREEN

(3) TOGGLE CURSOR ON-OFF

(4) CALIBRATE WIDE ANGLE LENS

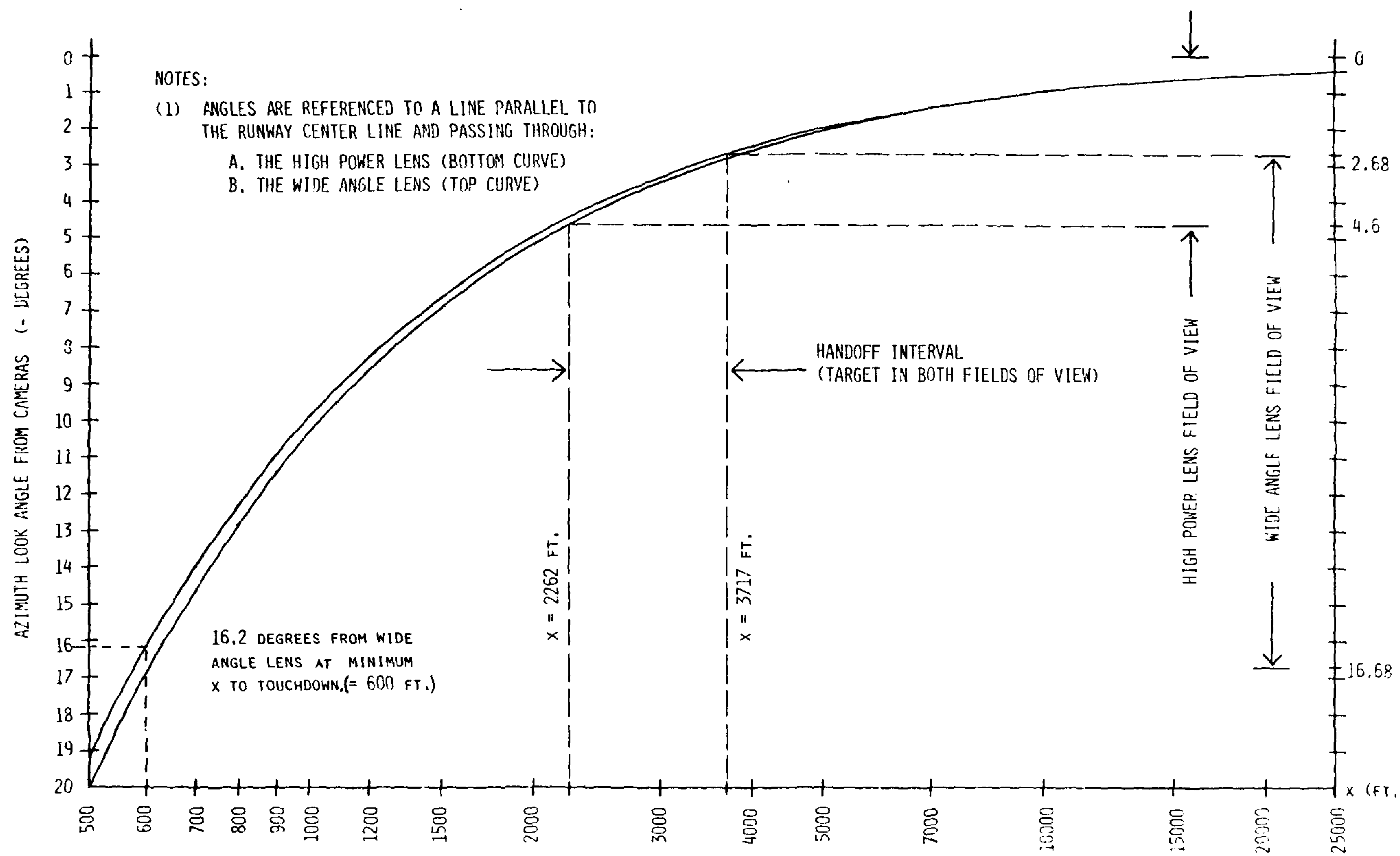

FIGURE 2.11. LOOK ANGLE TO TARGET VERSUS X.

Table 2.7
Recommended Calibration
Target Locations

Target Number	Rectangular Coordinates (feet, referenced to center of TPN-22 antenna. See Figure 2.6)		
	X	Y	Z
1	680.9	-2.4	15.0
2	680.9	-44.0	15.0
3	680.9	-199.1	15.0

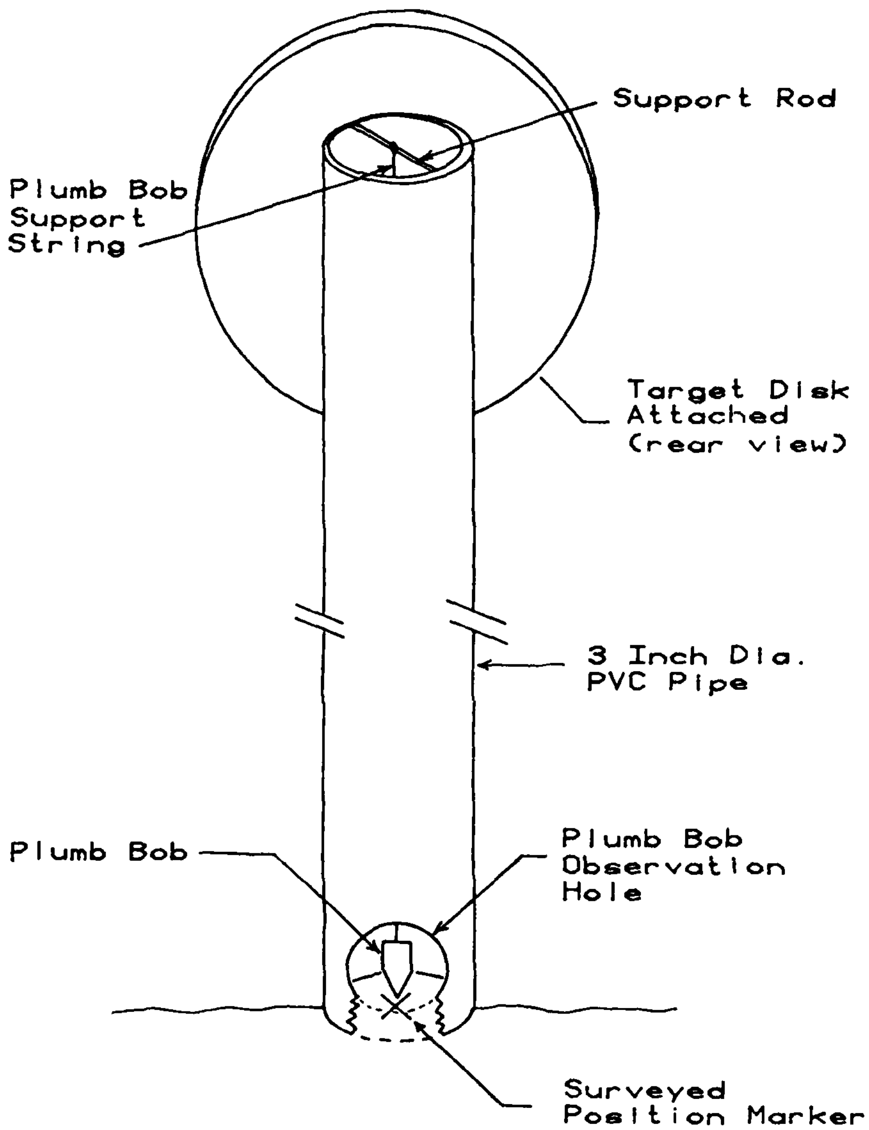

Figure 2.12. Recommended target stand construction.

(5) CALIBRATE NARROW ANGLE LENS

(6) TOGGLE LENS SELECTION

(7) RECALL PREVIOUS CALIBRATION

(8) STORE CURRENT CALIBRATION ON DISK

(9) DISPLAY CURRENT CALIBRATION

""CTRL C"" - RETURN TO CPM."

Step one is accomplished with the aid of selection two from the menu (move cursor function) in the following manner: (a) with one calibration target visible on the left of the screen and another visible are the right of the screen, move the cursor onto one reference target and note its VPIX coordinate; (b) move the cursor onto the other reference target and note its VPIX coordinate; and (c) for targets with equal z coordinates, the value for VPIX obtained in (a) and (b) above should be equal. If they are not, rotate the camera and repeat (a-c) until they are equal. Repeat this procedure for each camera.

The procedure for steps two and three is called out in prompts on the display instructing the user to move the cursor onto two reference targets for each camera. Following step two or three, the program outputs to the terminal elements of two linear maps, as shown below:

HOR PIXEL = MAZ * AZIMUTH ANGLE (RAD) + CAZ

VER PIXEL = MEL * ELEVATION ANGLE (RAD) + CEL

where MAZ (MEL) is the slope and CAZ (CEL) is the constant for the mapping of azimuth (elevation) angles into horizontal (vertical) picture elements for the selected camera.

To register the calibration, these values must be manually transported to the UYK-20's TV Tracker software. This calibration will remain valid unless either the cameras are relocated or reoriented or the UYK-20 software is changed.

Other selections are included in the calibration program menu. These self explanatory selections are not necessary to calibrate the system but are present for the convenience of the operator.

2.4.5 TRACKING

2.4.5.1 General

The track mode software incorporates the periodic repetition of the following five functions: (1) reading into memory the updated target and test run data from the UYK-

20 computer, (2) displaying updated test run data, (3) rewriting the cursor to the new target position, and (4) checking the console for in-track commands. The execution time of these functions places an upper limit on the overall update frequency. The consequence of the TV-Tracker receiving an update before completion of processing the previous update is discussed in Section 2.2.4.6.

2.4.5.2 Control and Execution in Track Mode

System control in the Track mode flows through a 'Track Loop' and a 'Command Loop' depending on I/O status as shown in Figure 2.4, the flowchart of the 'Track Executive'. I/O status is sensed by polling three latches (located physically within the TMS-5501 I/O controller chips on the Cromemco Tuart PC board) called the 'EFA latch', the 'ODA latch', and the 'Console Status Latch'. All three latches are cleared by software after a 'set' condition has been read from the latch.

Referring to Figure 2.4, control may be traced from entry into the Track mode. A menu of in-track commands is first displayed, then the EFA latch (which remembers if the UYK-20 has requested a data transfer) and the Console Status latch (which remembers if the console has received input) are alternately polled until a 'set' condition is sensed on one. If the EFA latch is set, the Tracker confirms the UYK-20 request to transfer data by testing the External Function code at the interface. If the External Function Code is valid, control is passed to the track loop. If the Console Status latch is set, control is passed to the command loop.

The track loop completes all of the primary functions outlined in Section 2.4.5.1, reads the EFA latch to see if an update has been missed, and then returns to the entry point. The command loop accepts a single letter input from the menu previously displayed, executes the function, and then returns to the entry point. In-track commands and their associated functions as listed in Table 2.8.

Table 2.8
In-Track Commands

Command	Function(s) Performed in Response to Command
'M'	M (Menu) clears the monitor screen and displays the 'Track' menu.
'S'	S (System menu) returns control to the user system executive and displays the system menu.
'W'	W (Wide angle lens) performs the same function as the "WL" system command explained in Table 2.5.
'L'	L (Long Lens) performs the same function as the 'LL' system command explained in Table 2.5.
'C'	C (Contouring) toggles on-off the contouring feature explained in Section 2.2.2.
'P'	P (Graphic Polarity) performs the same function as the 'WB' system command explained in Table 2.5.
'X'	X (Exchange Lens Selection) toggles the display between that obtained by executing the 'W' and 'L' commands mentioned above. A lens selection must have been previously made by any of the selection commands (WL, W, LL, L) or by processing data from the UYK-20 which contains a camera selection.
'A'	A reads one 26-byte message from the UYK-20 and displays the contents of the message in hexadecimal on the console.
'B'	B performs the function of A above repetitively to 'trace' the input data.
'T'	T performs the actual tracking function with test run data annotation in real time. See Section 2.4.5.

Note: Any on-line function will be terminated by any subsequent keyboard entry.

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SECTION 3
TECHNICAL ASSISTANCE TO NESEA

The task for technical assistance to NESEA was included to permit Georgia Tech to investigate areas of high interest to NESEA test personnel at Patuxent NAS and to provide a contractual vehicle for quick technical response to their changing needs. During the course of testing the TPN-22, it is inevitable that the test personnel will observe certain traits of the radar which demand improvement. The test center, however, does not have sufficient personnel to investigate many potential improvements. In this regard, Georgia Tech is able to study a problem theoretically and recommend action based on sound engineering judgement, and an unbiased observer point of view.

Early in the contract period, January 1980, NESEA listed three areas of high interest for Georgia Tech investigation. these included:

1. Multipath Investigation,
2. GAGC Investigation, and
3. Amplitude Processing Techniques.

Georgia Tech agreed initially to investigate the first two areas. During the course of the project, the GAGC study evolved into an amplitude processing investigation. The following subsections summarize the results of these three studies.

3.1 MULTIPATH INTERFERENCE INVESTIGATION

The TPN-22 precision Approach Radar (PAR) radar system is designed to automatically track and land aircraft from a distance of 10 nautical miles to within 300 feet of touchdown. In certain landing scenarios, the radar is required to perform very low angle tracking. Because of the low antenna height and high reflectivity of the runway, multipath interference effects present a serious source of tracking error, both at long ranges and just prior to touchdown. For this reason, the multipath problem was analyzed to determine the tracking situations affected, the magnitude of the effect, and potential methods of reducing the multipath associated errors.

The analysis indicated that a single fence placed at the average ground reflection point should provide a significant decrease in multipath interference effects. Quantitative improvements are documented in the Interim Technical Report for various landing offsets, fence positions, and glideslopes. A multipath fence has been fabricated by NESEA and will be used during the flight test program to be discussed in Section 3.4.

3.2 GAGC INVESTIGATION

The GAGC transfer curve measurements were repeated in August of 1981 to verify the experimental results obtained in May of 1980. The reader is referred to Section 4.2.4 of the Georgia Tech Interim Technical Report, June 1981, for a description of the earlier test and the experimental procedure. Data from that first experiment indicated that there was a long term drift phenomenon in the GAGC action which could not be explained, except by a malfunction of the GAGC circuit itself. The experiment was repeated, without the correlator, at pulse widths of 0.25 μsec (the nominal TPN-22 pulse width) and at 1.0 μsec, which was used in the prior procedure.

Three major conclusions may be drawn from the data:

1. There are significant differences in GAGC action for the 0.25 μsec and the 1.0 μsec pulse widths.
2. The August 1981 data are somewhat inconsistent with the May 1980 data.
3. The long term drift reported previously was again observed.

The difference between GAGC action for the two pulse widths becomes immediately apparent when the GAGC voltage is plotted as a function of input signal level as measured by the attenuator setting. Figure 3.1 shows that GAGC voltage for the narrower pulse increases at a lower input signal level than for the wider pulse. The difference in input signal level between the two cases is approximately 12 dB. This change may be explained if one postulates that the GAGC circuit integrates the received signal power (or voltage) for a minimum of one microsecond. A voltage thus obtained will be proportional to the energy in the signal pulse. Expressing the energy ratio (4 to 1) in voltage units and converting to dB (20 log 4) yields 12 dB, the measured difference.

Another anomaly is also shown in Figure 3.1. The shape of the curve for the August 1981 data is not the same as it was for the May 1980 data. This effect is

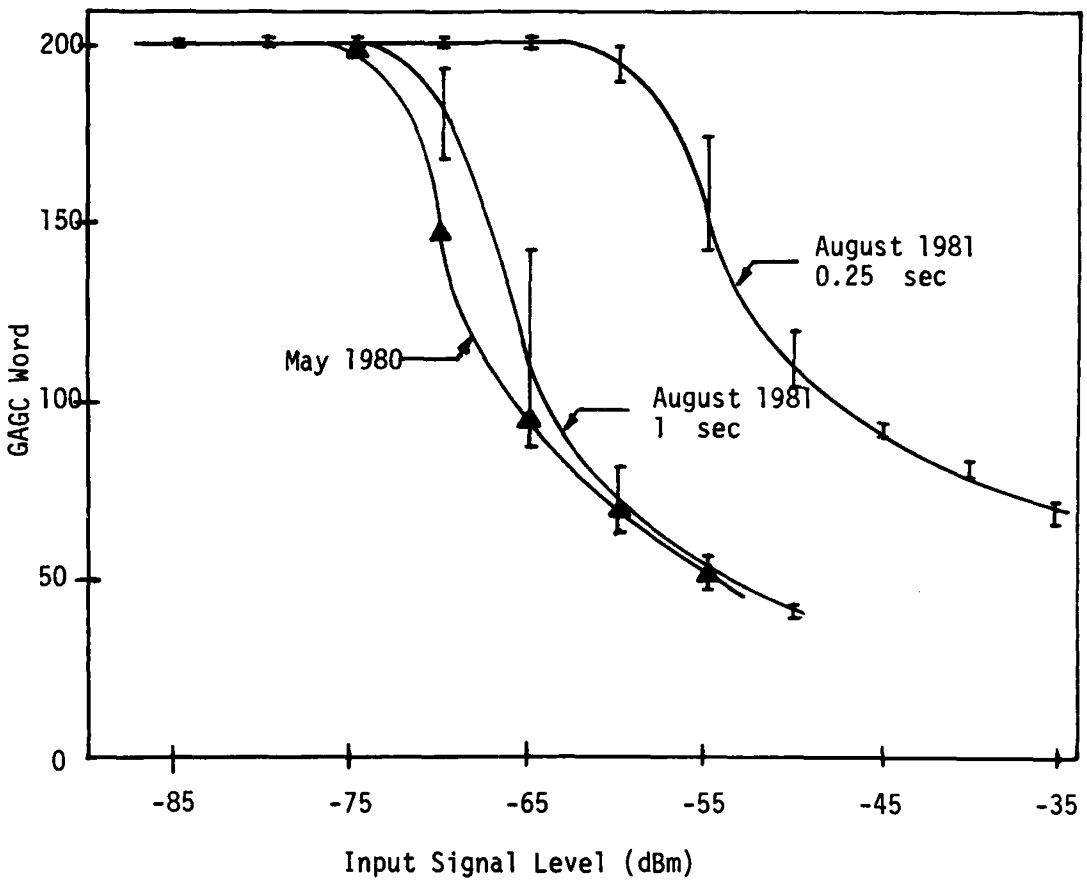


Figure 3.1 GAGC Word Versus Input Signal Level

probably due to long term drift in the GAGC circuit. A small change in slope should not have much effect on the tracking accuracy of the TPN-22.

The main purpose for repeating the GAGC experiments was to verify the existence of the coupled drift observed in the first test. Recall that the GAGC voltage and the near-plus-far video, the near video, and far video exhibited a coupled long term drift. The explanation for this drift could not be determined precisely, but all evidence points to a malfunction in the GAGC circuit itself. The results of the August 1981 test indicate:

1. The long term coupled drift was observed on many of the test runs, and
2. The one microsecond pulse width exhibited far worse coupled drift than the 0.25 microsecnd pulse width, but two cases of coupled drift in the narrower pulse were observed.

In conclusion, it is apparent that the overall behavior of the GAGC circuit is acceptable. However, the occurrence of the long term coupled drift could seriously affect the performance of the radar system. Therefore, its source should be identified and corrective action should be initiated as soon as possible.

3.3 AMPLITUDE PROCESSING TECHNIQUES

Target tracking performance should improve if use is made of the return signal amplitude as the TPN-22 performs a cross scan. Two conflicting points must be kept in mind and weighed when designing any such scheme. First, the signal-to-noise ratio is better at the inner beam positions, indicating that the return signal will be more dominated by the target signal and affected less by any interfering signals. On the other hand, the radar's antenna beam shape creates a larger error slope at the outer beam positions of each arm, which tends to minimize the effects of small noise-like fluctuations. The Interim Technical Report summarized several amplitude processing techniques and included an estimate of the improved performance for one of those techniques. A flight test program proposed to properly evaluate those approaches is described in the following subsection.

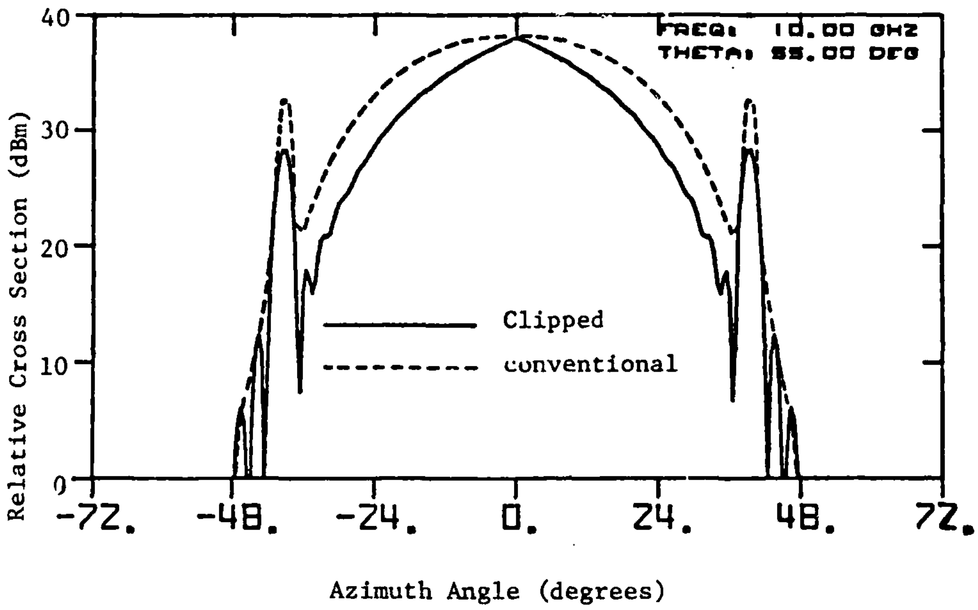
3.4 FLIGHT TEST PROGRAM

As noted in the Interim Report, gathering a statistically significant amount of flight test data is highly desirable. The data would be used to verify and test the multipath analysis and proposed multipath fence as well for evaluation of the proposed amplitude processing algorithms. It is imperative that enough flight passes along similar trajectories be flown to provide a statistically meaningful sample, so that random occurrences and transients will not unduly influence the analysis results. During these flights, a second sensor must be available to track the aircraft to provide absolute tracking data. Preferably, that sensor would be the laser tracker, but it could be the AN/SPN-42. In either case, a synchronized time clock, such as IRIG, must be included on the test data recordings to allow synchronized data to be obtained.

An additional enhancement to this series of flight tests is the inclusion of a circular polarization corner reflector, mounted behind the radome in the noise of the F-4 aircraft used for the tests. The corner reflector, with a radar cross section (RCS) of approximately 500 square meters, dominates the radar return from the aircraft (which has an RCS of approximately 10 square meters). During a landing approach, the change in attitude of the aircraft will not cause an apprecible change in the return signal level from the corner reflector; Figure 3.2 shows the relative cross section versus azimuth and elevation angle of the reflector to be fitted in the aircraft. Note that the corner reflector will be mounted in the aircraft such that it will be pointing directly at the radar during a normal three degree glideslope landing at a range of about one-half mile. With the corner reflector installed, the aircraft should emulate a point reflector, not subject to the target induced tracking errors of scintillation or glint. We will thus be able to separate environmental induced errors (clutter, multipath) and radar errors (servo lags, quantization, etc.) from target induced errors and, further, to separate multipath interference from all the other errors through the use of the multipath fence.

Design of the corner reflector is complicated because the TPN-22 radar utilizes circularly polarization, requiring the use of conducting vanes in the open face of a trihedral corner reflector to reflect the appropriate sense of circular polarization. A complete analysis was presented in the Interim Report.

The flight test program was designed to maximize the amount of statistically significant data so that the effects of the different sources of tracking errors could be accurately determined during post-flight analysis. The testing program was discussed



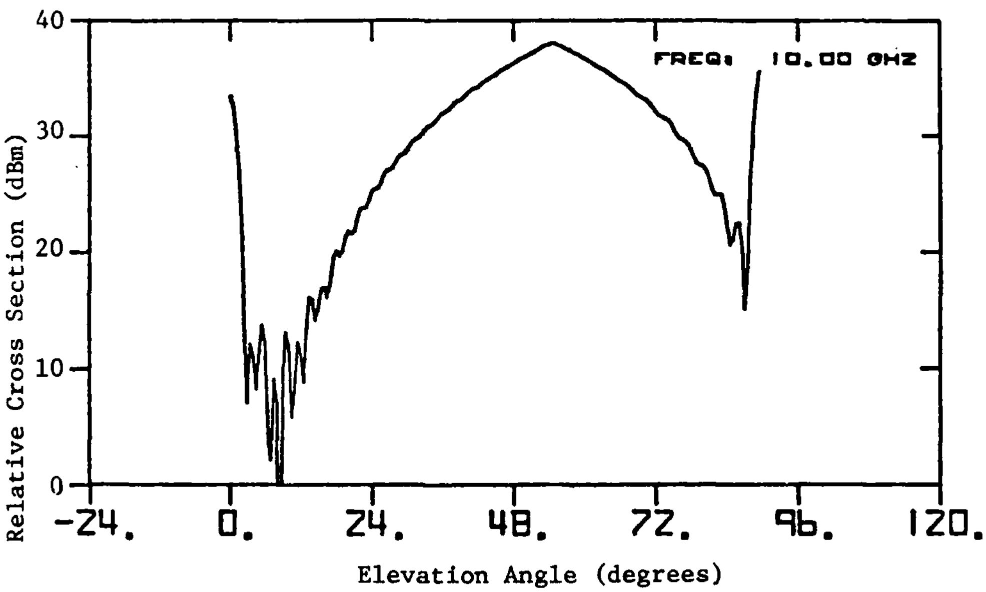


Figure 3.2 Azimuth (Upper) and Elevation (Lower) Backscatter Patterns for MATCALS Corner Reflector.

with NESEA personnel in December 1981 when the flight tests were first attempted. Due to inclement weather and mechanical failure in the aircraft, the tests were not accomplished. The tests will be rescheduled early in the next contract period.

The test program consists of two days of flights. The first day's passes will be made with the corner reflector mounted behind the aircraft radome, while the second day's passes will be made without the reflector. Table 3.1 summarizes the proposed flight tests.

TABLE 3.1

PROPOSED FLIGHT TEST PROGRAM

Event	Day	Number Passes	Corner Reflector	Multipath Fence	Offset to T.D.	Height to 3^0 Glide Slope
1	1	6	IN	@310'	750	600
2	1	4	IN	NO	750	600
3	1	5	IN	@430'	1500	600
4	1	5	IN	NO	1500	600
5	2	6	OUT	@310'	750	600
6	2	9	OUT	NO	750	600
7	2	5	OUT	NO	750	1000

The test flights are to begin on profile at 6 nmi from touchdown, and continue to touchdown. An elevated touchdown will not provide multipath data near touchdown but will be acceptable for the first few runs until the aircraft reaches the maximum touchdown weight limit. Note that a hot refuel is required between events 2 and 3 on the first day and in the middle of event 6 on the second day.

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SECTION 4
AIR TRAFFIC CONTROL

Georgia Tech was tasked by NAVELEX to perform an investigation of air traffic control sensors for the MATCALS program, specifically airport surveillance radars (ASR) and radar beacon systems (RBS). The investigation for both radar and beacon subsystems was to include baseline system performance specifications, a survey of candidate vendor products, evaluations of product capability, and recommendations for MATCALS incorporation.

We assumed for this MATCALS application that the ASR and RBS antennas would be colocated with the beacon antenna riding "piggyback" atop the radar antenna. While sensor synchronization is feasible with separate antenna systems, with independent rotation rates and transmission rates, there is no compelling reason to justify decoupled antennas. The tactical utilization of MATCALS, in fact, suggests common rotation on the same axis in a coupled fashion.

The beacon has been defined as the primary MATCALS air traffic control sensor, with the radar designated as a tertiary sensor, after TADIL radio communication. The need for radar capability is justified on the basis of control of aircraft lacking transponder capability, both civilian without the hardware and military without operative hardware. MATCALS operation in continental United States (CONUS) airfields requires compatibility with Federal Aviation Administration (FAA) air traffic control guidelines, specifically component redundancy in critical system operation.

The investigation of radars and beacons for MATCALS was divided, quite naturally, into two separate studies: radar and beacon. Baseline performance specifications for each were established using the MATCALS Specific Operational Requirement (SOR 34-22) as a guideline. Extrapolations of the SOR and additions to it were made with the cognizance of NAVELEX. The following subsections describe the details of these investigations and the conclusions which were drawn. A first-cut investigation of the impact of the Discrete Address Beacon System (DABS) was summarized in the Interim Technical Report.

4.1 AIRPORT SURVEILLANCE RADAR INVESTIGATION

4.1.1 INTRODUCTION

The Naval Electronic Systems Command generated a MATCALS Specification identified as Specific Operational Requirement (SOR) 34-22 dated 12 July 1973. Parts of this SOR identify the requirements for a skin track Airport Surveillance Radar (ASR). Three significant SOR statements relevant to the ASR are: (1) there will be an ASR; (2) the ASR will operate in a benign (i.e., no jamming) environment; and (3) the ASR is a backup to the Radar Beacon System and the Tactical Digital Data Link (TADIL) System.

Statement one mandates the existence of the ASR. An investigation of the need for the ASR was presumed to have been made before the SOR was written.

The benign environment of statement two permits the consideration of commercial ASR's from an understanding-of-radar-techniques-point-of-view. As realistic candidates for military operational environments, commercial ASR's are unacceptable because they are not engineered for rapid deployment and erection.

The backup role for the ASR defined for MATCALS in statement three perhaps lessens the incentives to pursue a maximum capability ASR. This role implies the use of an off-the-shelf ASR for MATCALS if minimum operational performance criteria are met.

The SOR defines an operational goal for the ASR:

> "The MATCALS ASR will detect and track all aircraft within the volume bounded by the radial distances of 0.5 and 60 nautical miles, the azimuthal angles of 0 to 360 degrees, and the elevation angles of 0.5 to 40 degrees with the exception that the maximum required coverage altitude is 40,000 feet."

This operational goal was used as a comparison standard for the radars investigated for MATCALS application. The comparison technique employed consisted of: (1) an analysis of each radar's performance in a standardized environment and (2) comparison of the radar's performance to the operational goal stated. Before this comparison was made, the operational goals for the radar and the radar environment were described in analytical terms.

The comparison methodology was to: (1) state the operational goal in radar performance terms, (2) model the radar and its environnment in a computer program, and (3) compare the MATCALS ASR operational goals to modeled radar performance.

4.1.2 OPERATIONAL GOALS IN RADAR TERMS

The required sequence of events for a radar which tracks a target are: (1) target illumination, (2) target detection, (3) target track, and (4) target identification. The first two events can be used to state the MATCALS ASR operational goal in radar terms. This statement consists of two parts: (1) what is the probability that the radar illuminated the target? and (2) given target illumination, what is the probability of target detection?

The radar and radar environment can be modeled so that the probability of illumination is expressed as the number of hits per scan. With these models the ASR operational goal can be represented, although incompletely, through a probability of detection. By tradition the probability of detection is usually set at 0.9, and this is the number stated in the SOR.

The selection of a probability of detection does not complete the ASR performance specification, because the number of false targets detected per unit time that will be tolerated must be specified. The value selected for this Probability of False Alarm (P_{fa}) was 1×10^{-7}, a value previously accepted by NAVELEX for the AN/TPS-65 radar for MATCALS.

Therefore, the operational goal can be restated:

> "The MATCALS ASR will exhibit a probability of detection of 0.9 per scan and a probability of false alarm of 1×10^{-7} for all aircraft within the volume bounded by the radial distances of 0.5 and 60 nautical miles, the azimuthal angles of 0 and 360 degrees, and the elevation angles of 0.5 to 40 degrees with the exception that the maximum required coverage altitude is 40,000 feet."

A first-cut baseline for the MATCALS Airport Surveillance Radar is described in detail in Appendix B, including relevant notes and rationales at the end.

4.1.3 RADAR MODEL

A basis for comparing surveillance radars is their radar average power-aperature product. This quantity is a measure of the energy available for reflection by a target. The energy reflected by a target relative to the noise energy within the radar's bandwidth is the factor that determines the probability of detection of a target.

Converting this generalized discussion into equation form entails several steps. Start with the conventional radar range equation:

$$R^4 = \frac{P_a \, G^2 \, \lambda^2 \, \sigma \, N E_i}{(4\pi)^3 \, k \, T_o \, B_n \, (F_n - 1) \, L_s \, f_r \, (S/N)}, \tag{4.1}$$

where

R	=	Range
P_a	=	Average power radiated
G	=	Antenna gain
λ	=	RF wavelength
σ	=	Target cross section
N	=	Number of pulses integrated
E_i	=	Integration efficiency
k	=	Boltzmann's constant
T_o	=	Reference temperature in degrees Kelvin
B_n	=	Noise bandwidth
F_n	=	Receiver noise factor
L_s	=	Miscellaneous losses
f_r	=	Pulse repetition frequency
S/N	=	Signal-to-noise ratio.

The antenna gain G can be expressed in terms of the antenna aperture A

$$G = 4\pi A/\lambda^2, \tag{4.2}$$

and the number of pulses integrated can be expressed in terms of the antenna beamwidth

$$N = \Theta^2 \, f_r / A_s, \tag{4.3}$$

where

A_s	=	Angular area to be scanned,
Θ^2	=	Beamwidth squared.

For a parabolic antenna, an approximate relationship between antenna gain G and beamwidth is

$$G = 41250/\theta^2 \; . \tag{4.4}$$

Substitution of Equations 4.2, 4.3, and 4.4 into 4.1 yields the expression

$$R^4 = \frac{P_a \; A \; 41250 \; \sigma \; E_i}{(4\pi)^2 \; k \; T_o \; B_n (F_n - 1) \; L_s \; (S/N)}$$

or $$R^4 = P_a \; A \; M/(S/N) \; , \tag{4.5}$$

where

$$M = \frac{41250 \; \sigma \; E_i}{k \; T_0 \; B_n \; L_S (F_n - 1) \; (4\pi)^2} \; .$$

Equation 4.5 states that the desired range for target detection is a function of only the average power radiated, the aperture of the antenna, and the required S/N. Moreover, since the selected S/N is a function of the probability of detection, then the inverse relationship can be expressed as

$$S/N = f^{-1} \; (P_d) \; . \tag{4.6}$$

Therefore, the final expression describing the desired maximum range R is

$$R = P_a \; A \; M/f^{-1}(P_d)^{1/4} . \tag{4.7}$$

Thus the selections of average power radiated, antenna aperture, and required probability of detection determine the range performance of the various radars performing the same search and acquisition function. A computer program which incorporates Equation 4.7 and other factors that describe the radar environment was used in this investigation to determine the range performance of candidate radars.

The required average power-aperture product for an ASR that will support the MATCALS operational goal is approximately

$$P_a A = 1046.9 \; (S/N) \; \text{watt-meter}^2$$

For a Swerling Case 3, a P_d of 0.9, a P_{fa} of 1×10^{-7}, and intergrating ten target returns, the S/N ratio required is 10 dB. The required average-power-aperture product is, therefore, equal to

$$P_a A = 10{,}469 \text{ watt-meter}^2.$$

4.1.4 RADAR ANALYSIS COMPUTER PROGRAM

The radar analysis computer program used for this ASR performance evaluation was created by personnel from the Radar Application Division (RAD) of the Georgia Tech Engineering Experiment Station (EES). The parent program is the radar performance prediction program (RGCALC) developed by L. V. Blake at NRL. Blake's work, RGCALC, and RGCALC decendents have been widely used throughout the radar community. The RAD computer program is titled MRANGE. MRANGE accepts radar descriptions, an environment description, and a target description, and uses these inputs to calculate probability of detection (P_d) as a function of range to a target. In these calculations the computer program evaluates factors such as (1) antenna pattern, (2) ground reflections, (3) radar horizon, (4) MTI filter response, (5) target velocity, (6) target cross section, (7) rain attenuation, (8) rain backscatter, (9) noise power enhancement due to rain, (10) target reflectivity statistics (i.e., Swerling Case), etc.

Each of the radars was modeled in mathematical terms acceptable to MRANGE. Where appropriate the radar descriptors were tailored to fit the constraints of MRANGE. For example, MRANGE does not have the ability to calculate pulse compression gains. These gains were calculated off-line and input into MRANGE as an increase in the radar's peak power.

Radar operation environments were also specified in terms acceptable to MRANGE. Four rainfall rate environments were modeled (0, 4, 25, and 50 millimeters per hour). The rain extent was 0 to 60 nautical miles for 4 millimeters per hour rainfall rate, 20 to 30 nautical miles for 25 millimeters per hour rainfall rate, and 25 to 30 nautical miles for 50 millimeters per hour rainfall rate. The program MRANGE treats the rain attenuation effects based on rain cell location, but it applies the rain clutter effects to all ranges. The placements of the rain cells were chosen to represent worst case conditions.

For the radars having circular polarization capability, the rain effects were modeled as a reduction of 15 dB in the rain backscatter, signal attenuation unchanged, and a target return reduced by 7 dB. These parameters are conservative as theoretical

analyses predict a time integrated cancellation ratio of 25 dB for light rain and 17 dB for snowflakes, with a concurrent target backscatter loss of 7 dB.

A separate computer program was written to calculate the rain velocity spread, the associated Doppler frequency spectrum, and the rain reflectivity as a function of Doppler frequency. This program was based on two empirical models of rain backscatter characteristics. The total reflectivity of the rain was calculated using the model presented in Section 17.4 of Skolnik's Radar Handbook. The spectral characteristics were modeled along the lines of Nathanson in Section 5.4 of his Radar Design Principles, assuming a linear wind shear model and an approximately Gaussian spectrum. The calculated rain reflectivity parameters were input to MRANGE through a one dimensional array.

The target radar cross section (RCS) was set at one square meter. It is well documented that the RCS of an aircraft is a complex function of frequency, aspect angle, and polarization. In the absence of a directive for more specific aircraft RCS characterization, the one square meter RCS was chosen because it represents the magnitude for a light aircraft in cruise trim at a nose-on aspect angle. The aircraft altitude was fixed at 5000 ft for these detection calculations.

The MRANGE program was modified to include the antenna elevation pattern of each radar system. Antenna pattern plots were obtained from each manufacturer, and computer arrays were established to model the patterns. Appropriate antenna gain values are obtained through linear interpolation between array data points.

An optional rain filter array was added to the MRANGE program tp permit software Doppler filtering of the received signals within a specified range interval. This rain filter processing operates independently of any MTI filtering which is active. Appropriate rain and MTI filtering data points are obtained through linear interpolation between array data points.

4.1.5 RADAR ANALYSIS RESULTS

A compilation of descriptors for nine airport surveillance radars is contained in Tables 4.1 through 4.5. These data were compiled from system descriptions, manufacturers' literature, technical orders, and telephone conversations with manufacturers' representatives. Comparisons between different radars must be tempered with the realization that manufacturers' performance specifications depend intrinsically on the criteria specified. The brief system descriptions which follow will assist the reader in making this desired comparison.

TABLE 4.1

ASR Performance Parameters

	ASR-443	ASR-7	ASR-8	GPN-24	ASR-9	TPN-24	TPS-44	TPS-59	TPS-65 (100 kW)	TPS-65 (25 kW)
Manufacturer	ITT Gilfillan	Texas Instruments	TI	TI	TI	Raytheon	Cardion	General Electric	Westinghouse	Westinghouse
Maximum Free Space Range-Specified (nmi)	60	(57)	60	60	55	60	110	190	80	56
P_d	.9	.75	.8	.9	.8	.9	.8	.8	.9	.9
P_{FA}	10^{-5}	10^{-6}	10^{-6}	10^{-5}	10^{-6}	10^{-5}	10^{-6}	10^{-6}	10^{-7}	10^{-7}
Target RCS (m^2)	2	2.2	1	1	1	1	2	1	1	1
Swerling Case	1	1	1	1	1	1	1	1	1	1
Maximum Free Space Range-Calculated (nmi)	(60)	29.1	67.7	49.3	48.2	64.1	62.6	100	100	78.1
P_d	.9	.9	.9	.9	.9	.9	.9	.9	.9	.9
P_{FA}	10^{-7}	10^{-7}	10^{-7}	10^{-7}	10^{-7}	10^{-7}	10^{-7}	10^{-7}	10^{-7}	10^{-7}
Target RCS (m^2)	1	1	1	1	1	1	1	1	1	1
Swerling Case	1	1	3	3	1	1	1	3	3	3
Range Resolution (m)	152	187	90	120	(158)	(150)	210	152	200	200
Range Accuracy (m)	± 23	$\pm .02$ R (± 1.2 nmi @ 60 nmi)	$\pm .25$nmi @ 60 nmi	$\pm .25$ nmi @ 60 nmi	56 m bias + 61 m jitter	± 40	± 93	± 18	± 38.5	± 38.5
Azimuth Resolution (deg)	(1.7)	2.25	(1.35)	(1.35)	(1.35)	2	(4)	(2.26)	(2.7)	(2.7)
Azimuth Accuracy (deg)	$\pm .17^\circ$	$\pm 1^\circ$	$\pm .5^\circ$	$\pm .5^\circ$	$\pm .5^\circ$	$\pm 5^\circ$	$\pm 1^\circ$	$\pm 1^\circ$	$\pm .2^\circ$	$\pm .2^\circ$
Elevation Beam Shape	csc^2	csc^2	csc^2	csc^2	csc^2	csc^2	csc^2	pencil	csc^2	csc^2
Elevation Coverage (deg)	.8-30	1-30	1-30	1-30	1-30	.5-30	.5-30	.8-20	.5-40	.5-40
Half-Power Azimuth Beamwidth (deg)	1.7	1.5	1.35	1.35	1.35	1.6	4	2.26	2.7	2.7
Dual or Single Beam	dual	single	dual	dual	dual	dual	single	single	single	single

TABLE 4.2
ASR Transmitter Characteristics

	ASR-443	ASR-7	ASR-8	GPN-24	ASR-9	TPN-24	TPS-44	TPS-59	TPS-65 (100 kW)	TPS-65 (25 kW)
RF Band	S	S	S	S	S	S	L	L	L	L
Transmit Frequency (GHz)	2.7 - 2.9	2.7 - 2.9	2.7 - 2.9	2.7 - 2.9	2.7 - 2.9	2.7 - 2.9	1.25 - 1.35	1.2 - 1.4	1.25 - 1.35	1.25 - 1.35
Polarization	V or C	V or C	V or C	V or C	V or C	V or C	H	V	V	V
Transmitter Type	Magnetron	Magnetron	VA-87E Klystron	JAN 8798 Magnetron	Klystron	Magnetron	QK358 Magnetron	Solid State Row Transmitters	Crystal Osc, TWT & CFA	Solid State
Peak Power (kW)	800	400	1,400	550	1,080	940	1,000	24.6	100	25
Average Power (kW)	.888	.334	.87	.4565	1.36	.525	1.12	Beam Managed	1, 2, or 3	.25, 5 or .75
Pulsewidth Before Compression (μ sec)	1.0	.833	.6	.8	1.05	1.0	1.4	51.2	13, 26 or 39	13, 26 or 39
Pulsewidth After Pulse Compression (μ sec)	-	-	-	-	-	-	-	.8	1.2	1.2
Duty Cycle (%)	.111	.0835	.0624	.083	.1134	.105	.112	Managed	1, 2 or 3	1, 2 or 3
Average PRF (Hz)	1,100	1,002	1,040	1,040	1,080	1,050	800	Managed	774	774
Type of Coherency	on receive	on receive	fully	on receive	fully	on receive	on receive	fully	fully	fully
Single or Dual Frequency on Transmission	single	single	dual	dual	single	single	single	dual	dual	dual

TABLE 4.3
ASR Receiver Characteristics

	ASR-443	ASR-7	ASR-8	GPN-24	ASR-9	TPN-24	TPS-44	TPS-59	TPS-65 (100 kW)	TPS-65 (25 kW)
Linear or Log	both	both	both	both	both	linear	both	linear	linear	linear
Dynamic Range (dB)	60	N.A.	80	80	80	28	65	70	60	60
First Blind Speed (knots)	914	(900)	2,150	900	(500)	1,100	3,000	2,500	800	800
MTI Ground Clutter Improvement (dB)	33.5	30	34	34	40	32	42	50	60	60
Sub-Clutter Visibility (dB)	(27.5)	25	28	28	(34)	25	20	(44)	(54)	(54)
Rain Integrated Cancellation Ratio (due to CP) (dB)	(30)	22	22	22	22	20	-	-	-	-
MTI Rain Clutter Improvement (dB)	-	-	-	-	-	(13-27)	-	35	35	35
STC Selectability	on/off	delay & slope	delay & slope	delay & slope	delay & slope	delay	on/off	on/off	slope	slope
Pulse Compression Ratio	-	-	-	-	-	-	-	64	13 piecewise	13 piecewise
FTC	yes	yes	yes	yes	yes	yes	yes	yes	no	no
IAGC	no	yes	yes	yes	yes	no	yes	no	no	no
ECCM	no	no	no	no	no	yes	no	yes	no	no

TABLE 4.4
ASR Physical Characteristics

	ASR-443	ASR-7	ASR-8	GPN-24	ASR-9	TPN-24	TPS-44	TPS-59	TPS-65 (100 kW)	TPS-65 (25 kW)
Prime Power Requirements	15 kW, 3φ 120/208V 60 Hz	N.A.	40 kW, 3φ 120/208V 50 or 60 Hz	15.2 kW, 3φ 120/208V 50 or 60 Hz	40 kW,3φ 120/208V 50 or 60 Hz	15 kW, 3φ 220V 50, 60 or 400Hz	10 kW, 3φ 120/208V 400 Hz	45 kW, 3φ 120/208 V 50 Hz	36 kW, 3φ 110/220V 60 Hz	16 kW, 3φ 110/220V 60 Hz
AC Power Requirements	N.A.	N.A.	16 kW	9 kW	10 kW	none	10 kW	17 kW	20 kW	20 kW
System Cooling	forced air	forced air	forced air	forced air	forced air	none	forced air	none	liquid cooled	forced air
Pressurized Waveguide	N.A.	yes	yes	yes	yes	yes	no	no	yes	no
Component Weights (lb)										
(1) Radar Building	8,500	-	-	16,500		6,500	4,180	11,300	13,800	12,000
(2) Antenna Group	-	-	-	11,000		-	3,950	8,500	-	-
(3) Addition Radar Equipment	4,000	-	-	2,400	N.A.	2,500	-	6,000	-	-
(4) Display Group	-	-	-	19,270		-	-	10,200	-	-
(5) Display Group		-	-	20,000		-	-	-	-	-
Component Dimensions in Meters (h x w x l)										
(1) Radar Building	2.4x2.4x6	-	-	2.4x2.4x9.1		2x2.2x3.7	2.3x2.2x3.7	3x3x6	2.4x2.4x6	2.4x2.4x6
(2) Antenna Group	-	-	-	2.7x2.4x4.3		-	2.1x2.2x3.8	3x x6	-	-
(3) Additional Radar Equipment	-	-	-	3x1.8x5	N.A.	2x2x4.3	-	3x3x6	-	-
(4) Display Group	-	-	-	2.4x2.5x9.5					-	-
(5) Display Group	-	-	-	2.4x2.5x9.6		-	-	3x3x6	-	-
Transportability										
(1) C-130	1	not transportable	not transportable	4	not transportable	1	1	5	1	1
(2) M-35 with Mobilizer	-			-		1	1	-	-	-
(3) Commercial Tractor-Trailer	-			-		1	1	-	1	1
(4) Commercial Flatbed	-			4		1	1	4	1	1
Deployment										
(1) Number of Men	4	N.A.	N.A.	6	N.A.	5	4	8	4	4
(2) Length of Time (hrs)	2			48*		80 min	40 min	2*	1	1

*Site Preparation Not Included

TABLE 4.5
ASR Reliability and Maintainability

	ASR-443	ASR-7	ASR-8	GPN-20	ASR-9	TPN-24	TPS-44	TPS-59	TPS-65 (100 kW)	TPS-65 (25 kW)
MTBR (hr)	N.A.	N.A.	633	962	1,000	650	800	809	556	(1,000)
MTTR (min)	N.A.	N.A.	25	14	30	14	30	40	30	N.A.
Single Transmitter Failure Mode	step function	step function	step function	step function	step function	step function	step function	graceful	step function	graceful
Unit Cost	N.A.	N.A.	$1.5M	$3-4M	N.A.	N.A.	$1M	$9M	$2.6M	$2.1M
Number Units Sold To Date	N.A.	N.A.	86	53	N.A.	11	26	15	20 (TPS-63's)	N.A.
Purchaser(s)	N.A.	FAA	FAA	USAF	(FAA)	USAF	USAF	USMC	USMC	N.A.

The ASR-443 is the designation given to a radar being developed by ITT Gilfillan, partially through internal research and development funding. This radar system is included in the tabular listings, but its detection performance was not computed since several relevant system parameters were not known. The ASR-443 is estimated to have a lower average power-aperture product than the ASR-8, and is projected to have less detection capability also.

The ASR-7 is a Federal Aviation Administration (FAA) radar for commercial airports. This radar was manufacturered by Texas Instruments and is currently used at many civilian airport facilities. The ASR-7 has been superseded by the ASR-8 and is no longer manufacturered. While the ASR-7 is obviously not a candidate for MATCALS air traffic control, since it is neither militarized nor even available, this system was included in these analyses as a reference point for system performance comparison.

The ASR-8 is an FAA radar manufactured by Texas Instruments and is essentially an upgraded version of its predecessor, the ASR-7. This radar is the newest airport surveillance radar used in civilian applications in the United States. Inclusion of the ASR-8 in this evaluation task is also for comparison purposes, since this system represents current FAA-acceptable performance standards.

The GPN-24 is an Air Force ASR manufactured by Texas Instruments and is a militarized version of the ASR-8. The significant difference between these two radar designs is that the GPN-24 uses a magnetron power source with approximately half the output power capability of the klystron used in the ASR-8. The first GPN-24 systems were installed during 1980, and production is expected to continue for several years.

The ASR-9 is the FAA designation for the next airport surveillance radar development. Performance standards for the ASR-9 have gone through several rounds of FAA specification publications followed by manufacturer comments and exceptions. These radar specifications were also used for performance evaluation as a reference point for FAA-desired level of capability.

The TPN-24 radar is the airport surveillance radar component of the Air Force TPN-19 air traffic control system and is manufactured by Raytheon. Another version of this radar, designated the ASR-910, has also been defined for the export market.

The TPS-44 is an Air Force, tactical ASR manufactured by Cardion. Twenty-six units of this system have been delivered to date. This system is designed for mobility and ease of deployment.

The TPS-59 is a solid state, phased array, surveillance radar built by General Electric for the Marine Corp. The design criteria for this radar far exceed those of

MATCALS, but the TPS-59 was included in this evaluation at NAVELEX request. Several versions of the TPS-59 have been manufactured, including an export market system included in the MATCALS evaluation.

The TPS-65 is a Marine Corps airport surveillance radar built by Westinghouse and was the originally designated MATCALS ASR. The TPS-65 is essentially a dual channel TPS-63, a system which was already in the Marine Corp inventory at the time of MATCALS definition. Several versions of the TPS-65 were included in this evaluation: the original MATCALS crossed field amplifier (CFA) radar; a 50 kilowatt, solid state transmitter system; a 25 kilowatt, solid state transmitter system; and a 12 kilowatt, solid state transmitter system.

Further discussion of the parameters presented in Tables 4.1 through 4.5 will assist the reader's appreciation of each radar system's performance characteristics. The first set of parameters in Table 4.1 includes the probability of detection P_d, probability of false alarm P_{fa}, target radar cross section, and Swerling target model values as specified by the manufacturer for calculation or determination of maximum free space range. Values enclosed in parentheses are assumed or implied, rather than actually specified. The next set of parameters in Table 4.1 repeats these same radar characteristics, except that the maximum free space ranges listed are those values calculated by MRANGE assuming a 0.9 P_d, a 10^{-7} P_{fa}, and a 1 square meter target cross section. The Swerling target model used in the calculations always reflects each radar's best possible detection performance. Note that all radars, except one, use a cosecant squared antenna beam pattern for elevation coverage, and several systems employ two beams. In this dual beam configuration, the lower beam position is used for transmit and receive modes, while the upper beam position is used for receive mode only.

Transmitter characteristics of these candidate radars are listed in Table 4.2. All of these radars operate at either S- or L-band. All S-band systems use circular polarization for rain backscatter rejection, while two of the L-band systems use signal filtering to accomplish the same result. All systems are coherent, although the magnetron-based systems operate in a coherent-on-receive mode.

Table 4.3 lists some of the radar receiver characteristics pertinent to ASR operation. The rain integrated cancellation ratio (ICR) is a measure of a system's capability of rejecting rain backscatter. One sense circular polarization is used for transmission and reception, while the rain backscatter signal will be primarily of the cross polarization sense. Thus, the ICR figure is a measure of polarization integrity of the antenna over its entire antenna pattern. A fast-time-constant (FTC) capability

indicates a signal processing technique for RF interference rejection. Capability for instantaneous automatic gain control (IAGC) permits attenuation of extended clutter returns.

Table 4.4 summarizes the physical characteristics of the candidate airport surveillance radars for MATCALS. Transportability and speed of deployment are the key features listed. The MATCALS SOR refers to a 12,000 pound weight limit and transportability by C-130, helicopter, and tractor-trailer. A set-up time of one hour is the goal for system deployment after delivery of all components at the site.

Table 4.5 summarizes system reliability data, as provided by each manufacturer, including mean-time-between-failures (MTBF) and mean-time-to-restore (MTTR). Transmitter/receiver redundancy is required to meet FAA requirements for CONUS operation. Note that the TPS-59 and solid state versions of the TPS-65 do not include redundancy in transmitter design, as transmitter failure would occur in a module by module fashion. Unit cost estimates were also provided by the manufacturers, but should be interpreted as rough estimates only.

The MRANGE computer program was used to generate the detection performance curves shown in Figures 4.1 through 4.35. Each curve represents probability of detection (ordinate) versus range (abscissa) for a radar with a specified polarization and either single or dual frequency operation (Swerling Case 1 or Case 3, respectively).

Each upper curve represents detection performance as a function of range under free space conditions, i.e., atmospheric attenuation and earth proximity effects are ignored. The antenna beam pattern maximum is always on the target, and linear polarization operation is assumed. The 0.8 Pd and 0.9 P_d points are calculated by interpolation between data points and are marked in range on the graph.

Each lower curve represents detection peformance as a function of range when atmospheric attenuation and earth proximity effects are included. The curve marked "Clear Air" represents detection performance calculated with standard atmospheric absorption, but no rain, and linear polarization. The three other curves are designated by rainfall rate, in millimeters per hour, and polarization. The 0.8 Pd and 0.9 P_d points are calculated for all four environment conditions for "solid" detection. The 4 millimeter per hour rainfall region extends from 0 to 60 nautical miles; the 25 millimeter per hour rainfall rate extends from 20 to 30 nautical miles; and the 50 millimeter per hour rainfall rate extends from 25 to 30 nautical miles.

The aircraft is defined to fly toward the radar at a constant altitude (5000, 10,000, 20,000, 30,000, and 40,000 ft for these graphs) so that the aircraft crosses the

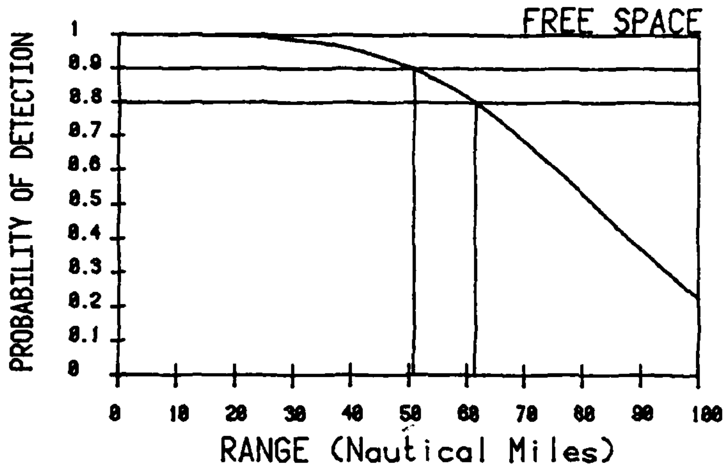
radar horizon near a range of 85 nautical miles. While the aircraft is near the radar horizon, the direct radiation path length to the target and the indirect path length of the radiation from a reflection off the earth's surface are less than a small fraction of a wavelength different. The constructive interference (commonly called a multipath peak) that results from this condition causes an artifically high P_d in the range region of 75 to 85 nautical miles. Closer to the radar, the path length difference approaches a half wavelength, resulting in destructive interference (a multipath null) and a low P_d near 70 nautical miles range. At still nearer ranges, the P_d tends to increase as the distance to the aircraft decreases.

In the "All Factors" scenarios, rainfall conditions imply circular polarizations for those radar systems which have that capability. The mathematical implementation of circular polarization in the computer model MRANGE included lowering the rain backscatter reflectivity η by 15 dB (to reflect a nominal radar ICR for all three rainfall scenarios) and lowering the aircraft radar cross section by 7 dB to 0.2 square meters (to reflect target backscatter depolarization).

Computations of aircraft detection performance were performed for the four militarized airport surveillance radars identified previously in the Interim Technical Report: the GPN-24, the TPN-24, the TPS-44, and the TPS-65. Four versions of the TPS-65 were evaluated, each differing essentially only in peak transmitted power.

Figures 4.1 through 4.5 depict the aircraft detection performance for the GPN-24, which is essentially a militarized version of the FAA ASR-8, but utilizes a magnetron instead of a klystron transmitter. The linear polarization, free space detection ranges, for detection probabilities of 80 and 90 percent are 61.30 and 50.75 nautical miles, respectively. A Swerling 1 target model is assumed for single frequency operation, although S/N gain can be achieved if two frequency operation is used, justifying a Swerling 3 target model.

With all factors included in the computations, the 80 and 90 percent detection probabilities occur respectively at 43.59 and 38.72 nautical miles in clear air and at approximately 31 and 28 nautical miles in rain, for a 5,000 ft aircraft elevation. Circular polarization is assumed in all rainfall scenarios. At a 10,000 ft aircraft elevation, the clear air detection ranges occur at 51.68 and 44.66 nautical miles, reflecting the effects of the aircraft in a higher gain section of the antenna pattern than the 5,000 ft elevation case. Rainfall detection ranges are approximately 35 and 29 nautical miles at 10,000 ft altitude.



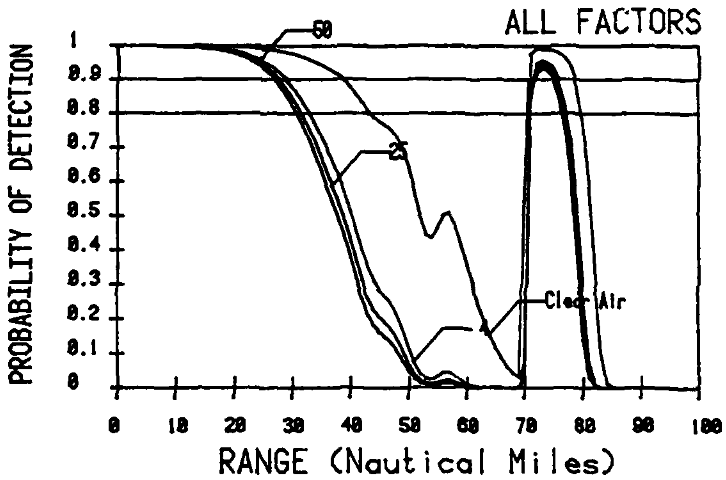
Radar: AN/GPN-24

Altitude = 5,000 feet

Comment: OUTPUT POWER IS 550 KW. THE POLAR. IS CIRCULAR (EXCEPT CLEAR) AND THE TARGET FLUCT. IS SWERLING 1.

80% , 90% PD Ranges (Free Space) = 61.30, 50.75 nmi

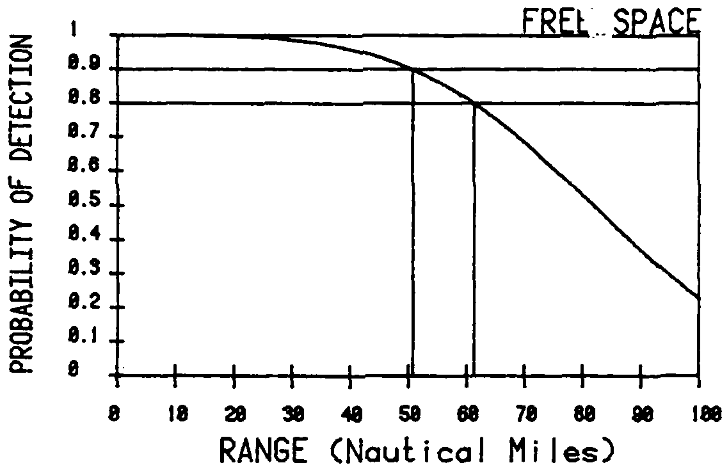
These data were calculated on 120381



80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 43.59, 32.95, 31.58, 30.79 nmi

90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 38.72, 28.94, 27.74, 27.04 nmi

Figure 4.1. Calculated GPN-24 Detection Performance, 5000 ft Altitude.



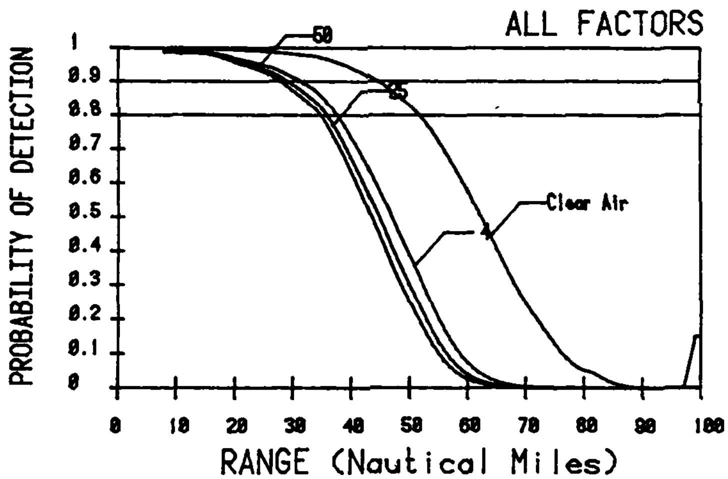
Radar: AN/GPN-24

Altitude = 10,000 feet

Comment: OUTPUT POWER IS 550 KW. THE POLAR. IS CIRCULAR (EXCEPT CLEAR) AND THE TARGET FLUCT. IS SWERLING 1.

80% , 90% PD Ranges (Free Space) = 61.30, 50.75 nmi

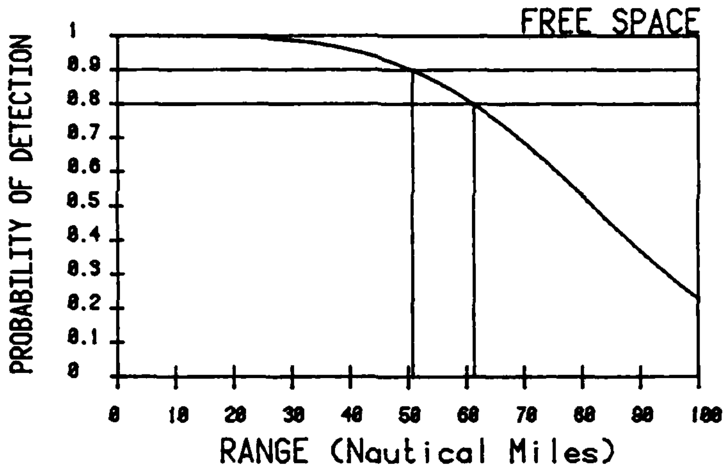
These data were calculated on 120381



80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 51.68, 37.56, 35.82, 34.78 nmi

90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 44.66, 31.39, 29.13, 27.98 nmi

Figure 4.2. Calculated GPN-24 Detection Performance, 10,000 ft Altitude.



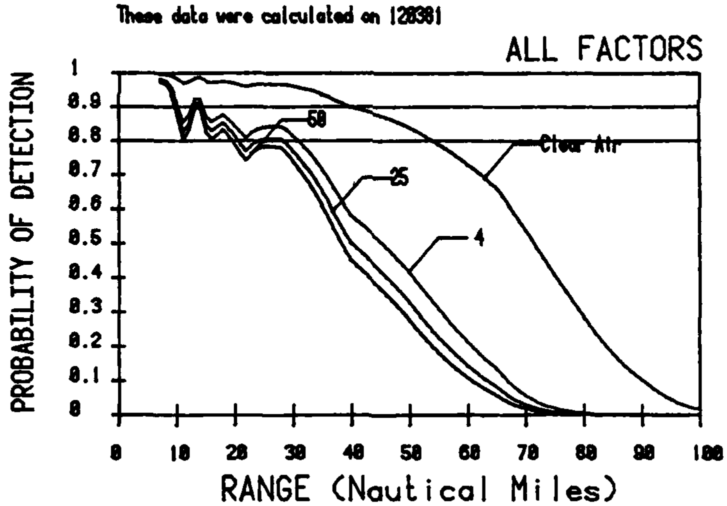
Radar: AN/GPN-24

Altitude = 20,000 feet

Comment: OUTPUT POWER IS 550 KW. THE POLAR. IS CIRCULAR
(EXCEPT CLEAR) AND THE TARGET FLUCT. IS SWERLING 1.

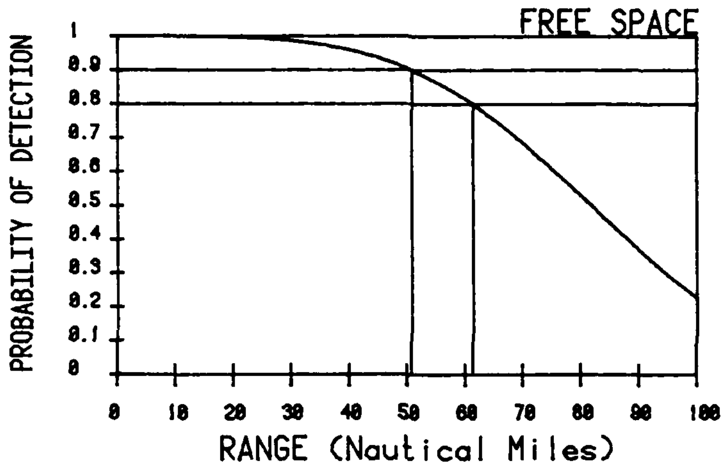
80% , 90% PD Ranges (Free Space) = 61.30, 50.75 nmi

These data were calculated on 120381



80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 54.10, 30.90, 20.69, 11.06 nmi
90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 39.91, 10.25, 9.95, 9.72 nmi

Figure 4.3. Calculated GPN-24 Detection Performance, 20,000 ft Altitude.



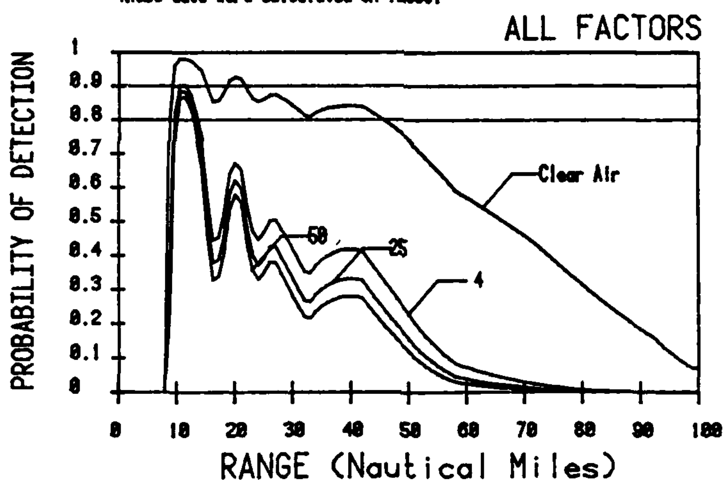
Radar: AN/GPN-24

Altitude = 30,000 feet

Comment: OUTPUT POWER IS 550 KW. THE POLAR. IS CIRCULAR (EXCEPT CLEAR) AND THE TARGET FLUCT. IS SWERLING 1.

80% , 90% PD Ranges (Free Space) = 61.30, 50.75 nmi

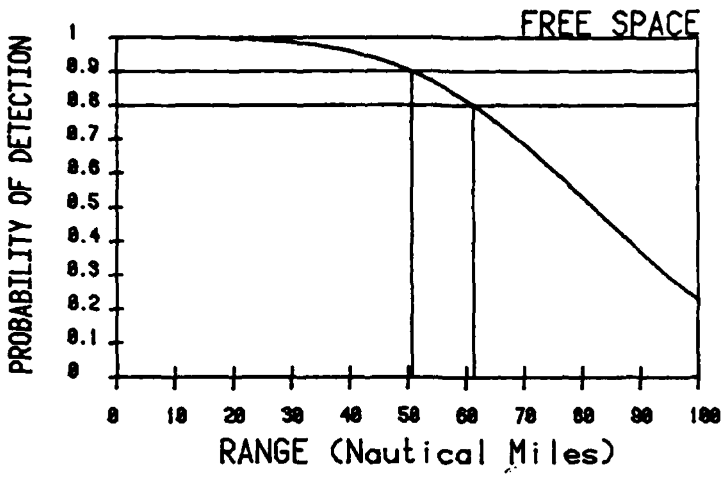
These data were calculated on 120381



80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 45.67, 13.55, 13.11, 12.77 nmi

90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 15.25, 11.55, 0.00, 0.00 nmi

Figure 4.4. Calculated GPN-24 Detection Performance, 30,000 ft Altitude.



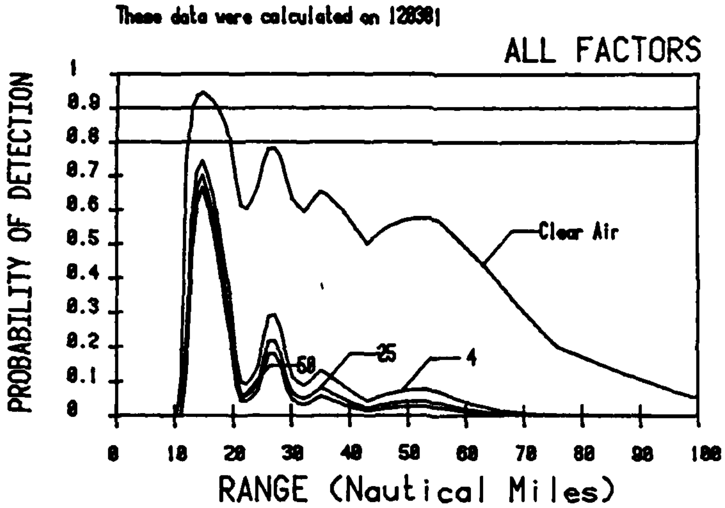
Radar: AN/GPN-24

Altitude = 40,000 feet

Comment: OUTPUT POWER IS 550 KW. THE POLAR. IS CIRCULAR
(EXCEPT CLEAR) AND THE TARGET FLUCT. IS SWERLING 1.

80% , 90% PD Ranges (Free Space) = 61.30, 50.75 nmi

These data were calculated on 120381



80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 19.56, 0.00, 0.00, 0.00 nmi

90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 17.19, 0.00, 0.00, 0.00 nmi

Figure 4.5. Calculated GPN-24 Detection Performance, 40,000ft Altitude.

At an aircraft altitude of 20,000 ft, the detection ranges in clear air are 54.10 and 39.91 nautical miles. Rainfall detection performance is poor due to the S/N losses incurred by the use of circular polarization.

At 30,000 ft altitude the clear air detection ranges fall to 45.67 and 15.25 nautical miles, while at 40,000 ft the clear air detection ranges are 19.56 and 17.19 nautical miles. Rainfall detection range at both altitudes is very poor. Note that at these two last altitudes aircraft flying closer than 10 nautical miles from the radar will be within the "cone of silence" of the radar, as defined by the elevation angle extent of the antenna coverage.

Figures 4.6 through 4.10 depict the detection performance computed for the TPN-24 radar at the same set of aircraft altitudes. Free space detection ranges occur at 71.96 and 64.29 nautical miles for 80 percent and 90 percent detection, respectively. A Swerling 3 target model was assumed, for dual frequency radar operation. The TPN-24 utilizes circular polarization for operation in rain.

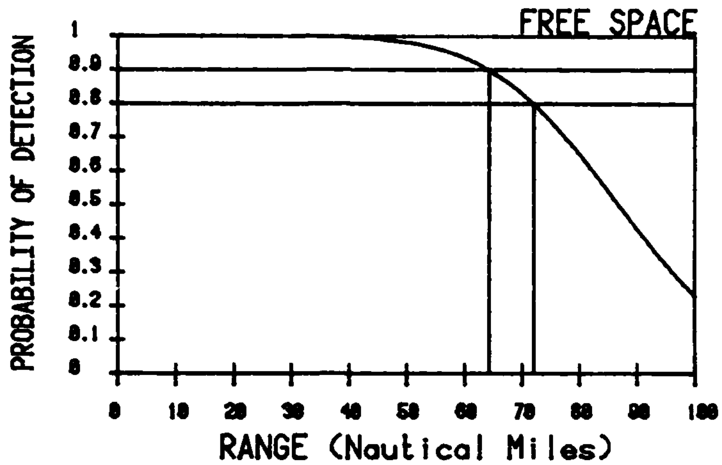
Detection performance at 5,000 ft aircraft altitude is characterized by a strong multipath interference peak near 70 nautical miles range, and a deep null between 50 and 60 nautical miles. Clear air detection ranges are 46.84 and 43.77 nautical miles for 80 percent and 90 percent detection, respectively. Detection in rain drops to approximately 35 and 33 nautical miles.

At 10,000 ft altitude, multipath interference effects are minimal, and clear air detection ranges are 57.96 and 54.45 nautical miles. Detection in rain is also improved to approximately 41 and 38 nautical miles. At 20,000 ft altitude, clear air detection ranges are 64.60 and 55.34 nautical miles, and performance in rain is approximately 27 and 14 nautical miles.

Antenna pattern effects become prominent at aircraft altitudes of 30,000 and 40,000 ft. Clear air detection ranges are 41.58 and 21.59 nautical miles at the former altitude and 20.18 and 19.15 nautical miles at the latter altitude. Detection performance in rain is very poor.

Figures 4.11 through 4.15 depict the detection performance computed for the TPS-44 radar, which does not have a circular polarization mode or a rain filter. Free space detection ranges are 67.55 and 55.94 nautical miles for 80 percent and 90 percent detection, respectively. Since the TPS-44 transmits a single frequency signal, a Swerling I target model is appropriate.

At a 5,000 ft target altitude, there is a multipath interference peak at 75 nautical miles and a null at approximately 69 nautical miles. Clear air detection ranges are 59.57



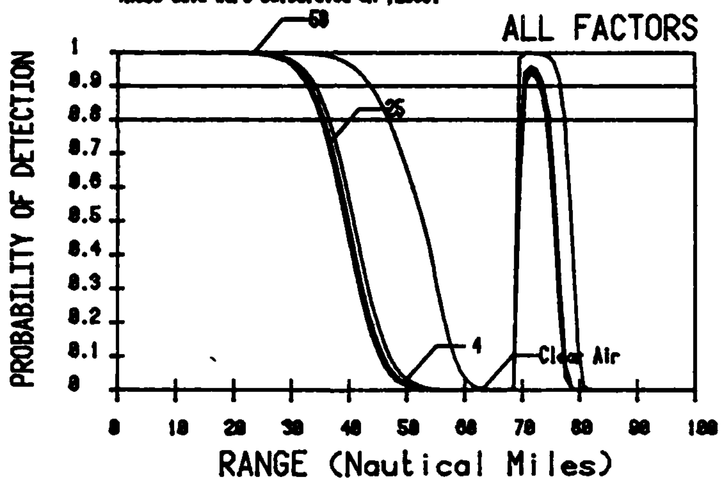
Radar: AN/TPN-24

Altitude = 5,000 feet

Comment: OUTPUT POWER IS 940 KW. THE POLAR. IS CIRCULAR
(EXCEPT CLEAR) AND THE TARGET FLUCT. IS SWERLING 3.

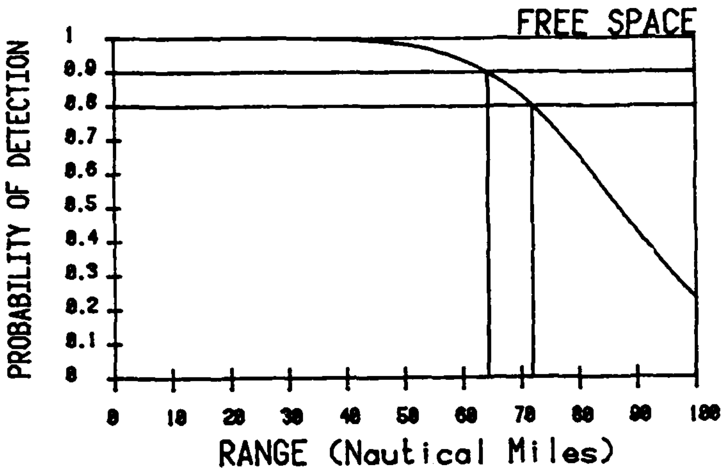
80% , 90% PD Ranges (Free Space) = 71.96, 64.20 nmi

These data were calculated on 120381

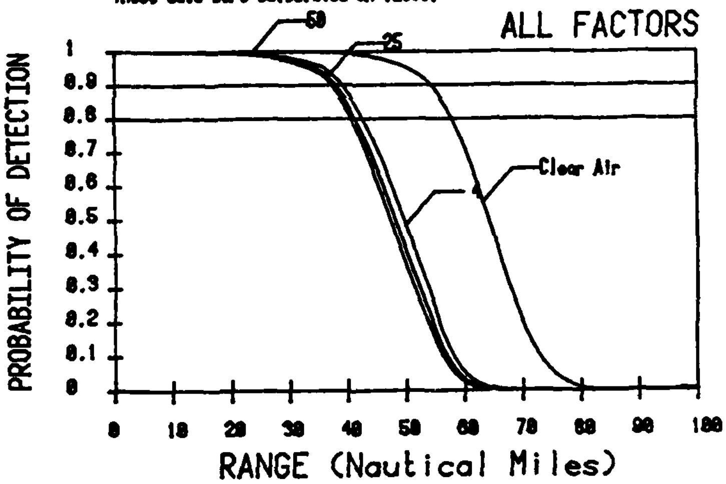


80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 40.04, 36.40, 35.60, 35.13 nmi
90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 43.77, 34.00, 33.25, 32.03 nmi

Figure 4.6. Calculated TPN-24 Detection Performance, 5,000 ft Altitude.

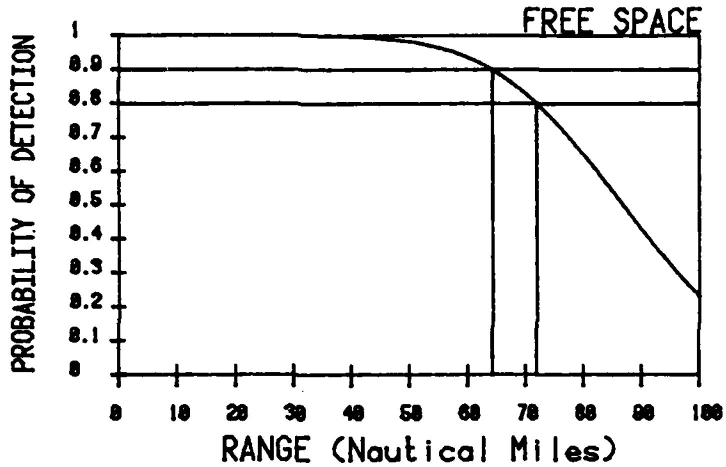


Radar: AN/TPN-24
Altitude = 10,000 feet
Comment: OUTPUT POWER IS 940 KW. THE POLAR. IS CIRCULAR
(EXCEPT CLEAR) AND THE TARGET FLUCT. IS SWERLING 3.
80% , 90% PD Ranges (Free Space) = 71.96, 64.20 nmi
These data were calculated on 120381



80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 57.96, 42.65, 41.51, 40.81 nmi
90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 54.46, 39.10, 37.97, 37.31 nmi

Figure 4.7. Calculated TPN-24 Detection Performance, 10,000 ft Altitude.



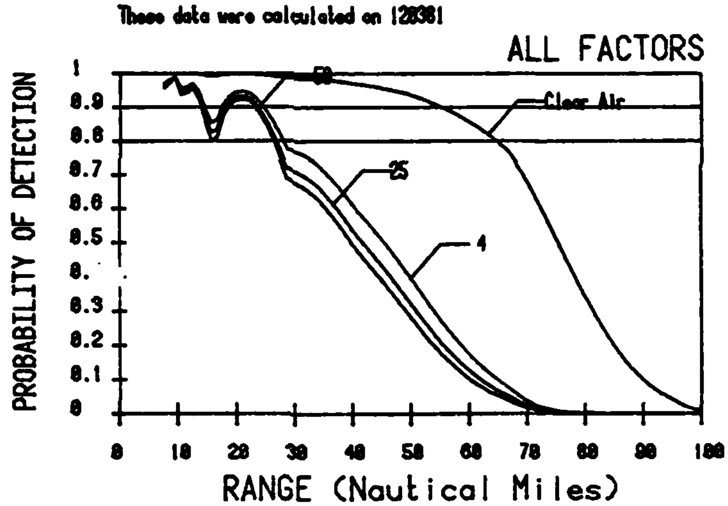
Radar: AN/TPN-24

Altitude = 20,000 feet

Comment: OUTPUT POWER IS 840 KW. THE POLAR. IS CIRCULAR
(EXCEPT CLEAR) AND THE TARGET FLUCT. IS SWERLING 3.

80% , 90% PD Ranges (Free Space) = 71.96, 64.28 nmi

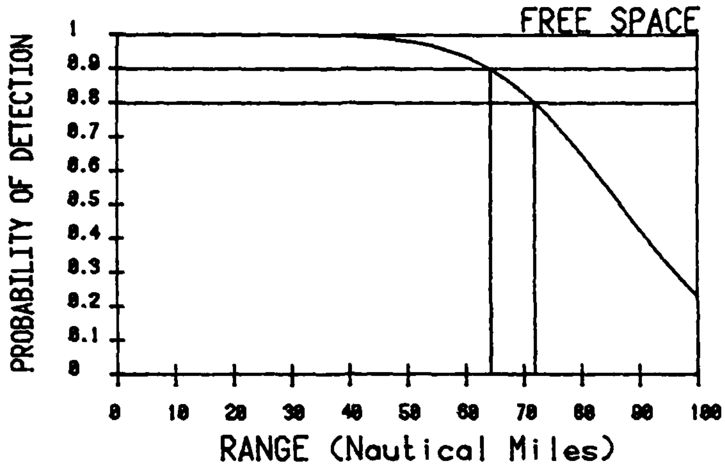
These data were calculated on 120381



80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 64.08, 28.00, 26.82, 26.37 nmi

90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 55.34, 14.46, 14.07, 13.83 nmi

Figure 4.8. Calculated TPN-24 Detection Performance, 20,000 ft Altitude.



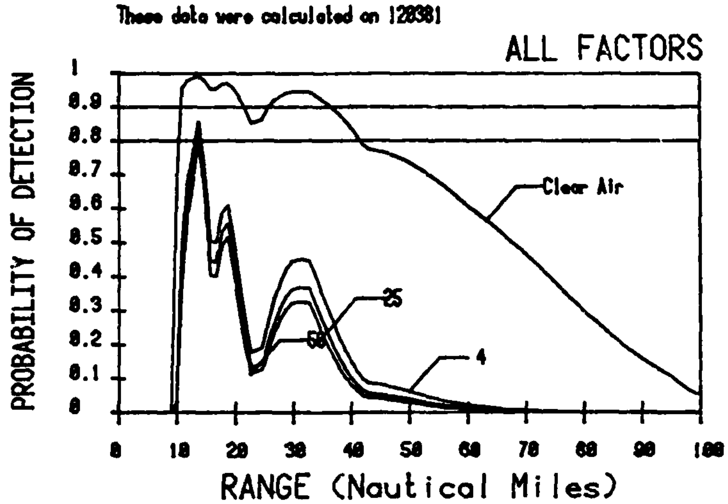
Radar: AN/TPN-24

Altitude = 30,000 feet

Comment: OUTPUT POWER IS 040 KW. THE POLAR. IS CIRCULAR (EXCEPT CLEAR) AND THE TARGET FLUCT. IS SWERLING 3.

80% , 90% PD Ranges (Free Space) = 71.96, 64.28 nmi

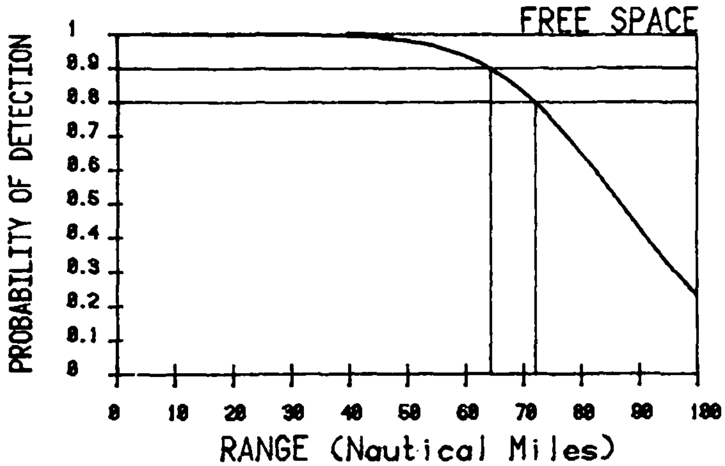
These data were calculated on 120381



80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 41.58, 14.19, 13.94, 13.79 nmi

90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 21.59, 0.00, 0.00, 0.00 nmi

Figure 4.9. Calculated TPN-24 Detection Performance, 30,000 ft Altitude.



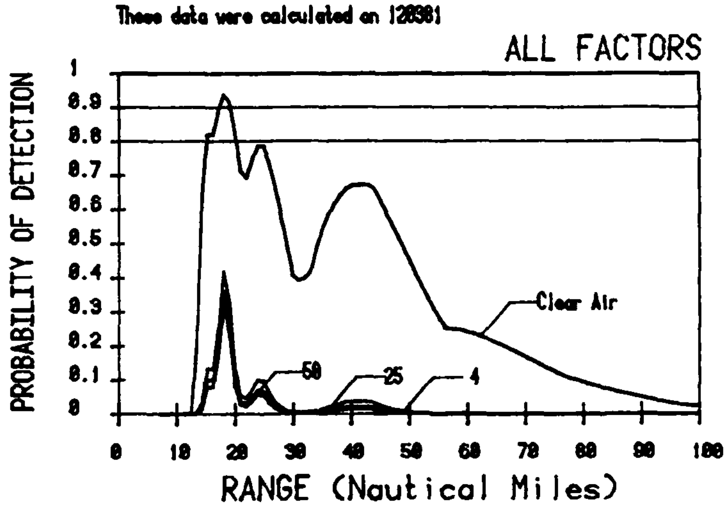
Radar: AN/TPN-24

Altitude = 40,000 feet

Comment: OUTPUT POWER IS 940 KW. THE POLAR. IS CIRCULAR
(EXCEPT CLEAR) AND THE TARGET FLUCT. IS SWERLING 3.

80% , 90% PD Ranges (Free Space) = 71.86, 64.29 nmi

These data were calculated on 120381



80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 20.18, 0.00, 0.00, 0.00 nmi
90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 19.15, 0.00, 0.00, 0.00 nmi

Figure 4.10. Calculated TPN-24 Detection Performance, 40,000 ft Altitude.

AD-A113 047 GEORGIA INST OF TECH ATLANTA ENGINEERING EXPERIMENT --ETC F/G 17/7
MARINE AIR TRAFFIC CONTROL AND LANDING SYSTEM (METCALS) INVESTI--ETC(U)
FEB 82 R N TREBITS, E S SJOBERG, R B EFURD N00039-80-C-0082
UNCLASSIFIED GIT/EES-A-2550-FTR NL

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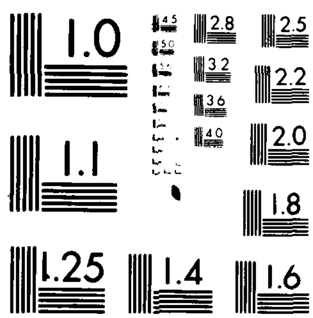
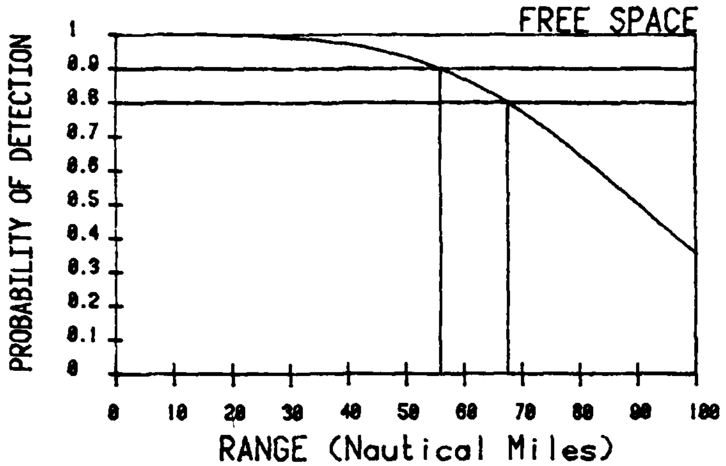


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A



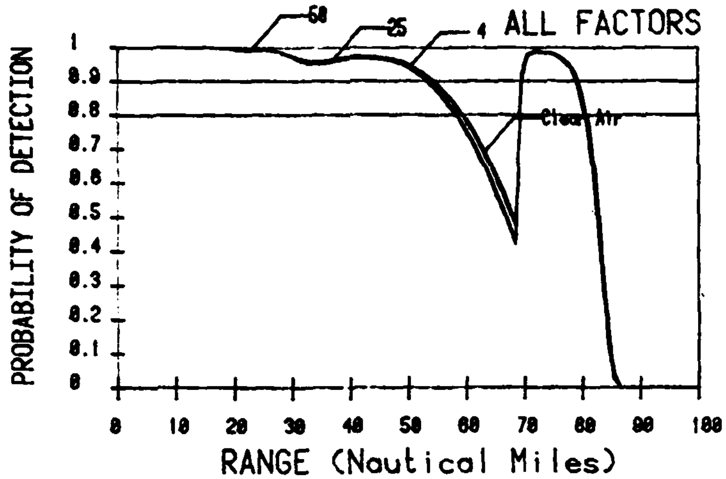
Radar: AN/TPS-44

Altitude = 5,000 feet

Comment: THE OUTPUT POWER IS 1000 KW. THE POLARIZATION IS LINEAR AND THE TARGET FLUCTUATION IS SWERLING 1.

80% , 90% PD Ranges (Free Space) = 67.55, 55.94 nmi

These data were calculated on 120381



80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 59.57, 59.29, 58.47, 58.22 nmi

90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 54.54, 54.30, 53.53, 53.29 nmi

Figure 4.11. Calculated TPS-44 Detection Performance, 5,000 ft Altitude.

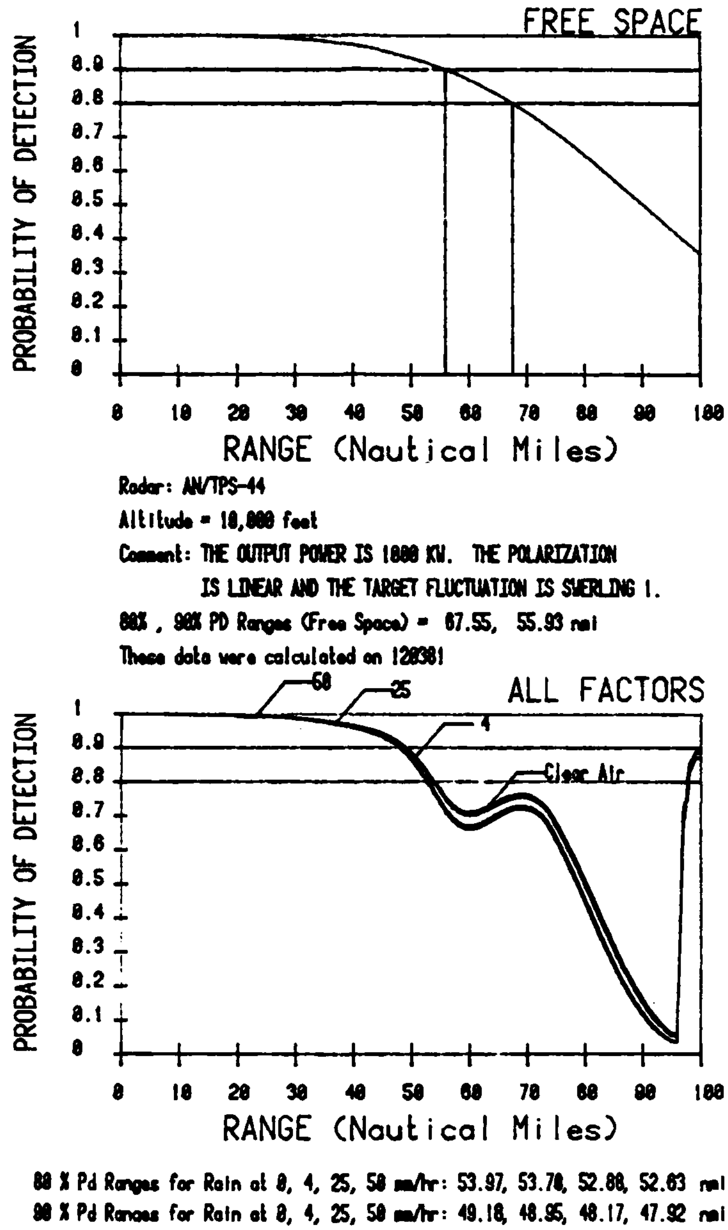
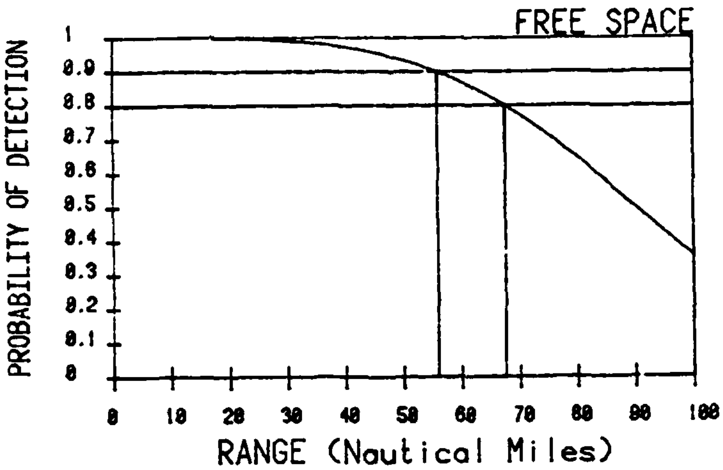


Figure 4.12. Calculated TPS-44 Detection Performance, 10,000 ft Altitude.



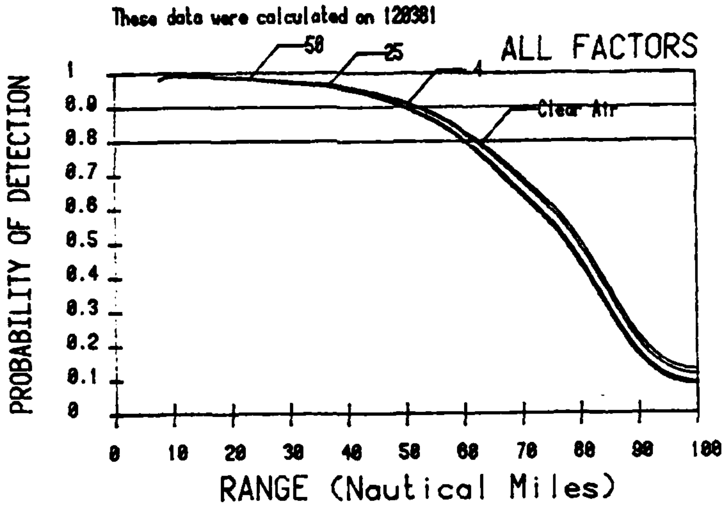
Radar: AN/TPS-44

Altitude = 20,000 feet

Comment: THE OUTPUT POWER IS 1000 KW. THE POLARIZATION IS LINEAR AND THE TARGET FLUCTUATION IS SWERLING 1.

80% , 90% PD Ranges (Free Space) = 67.50, 55.93 nmi

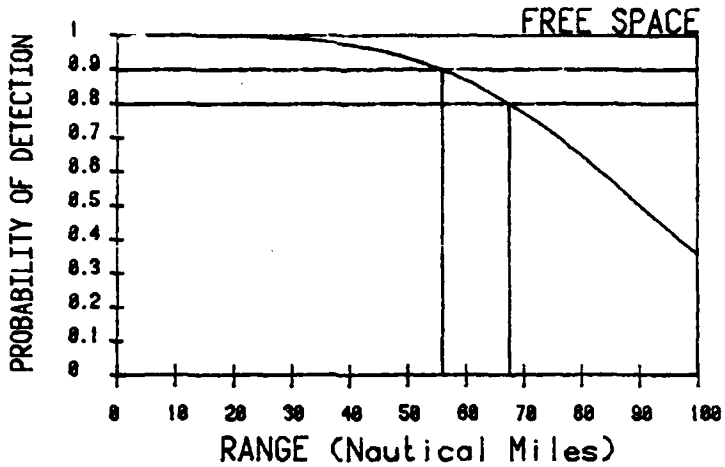
These data were calculated on 120381



80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 62.55, 62.00, 60.43, 59.95 nmi

90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 52.57, 52.07, 50.43, 49.94 nmi

Figure 4.13. Calculated TPS-44 Detection Performance, 20,000 ft Altitude.



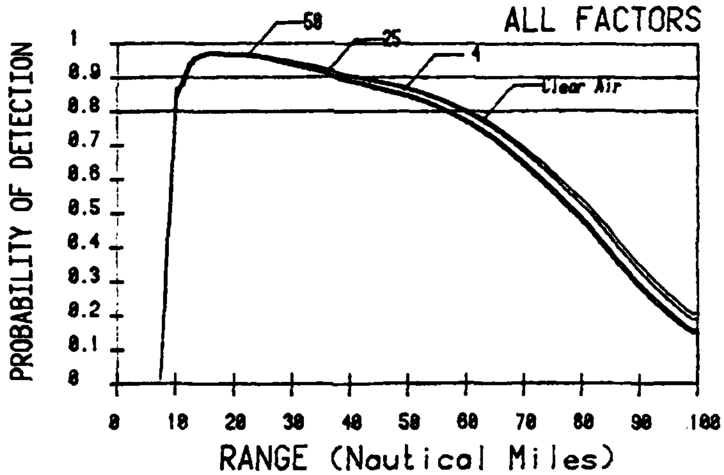
Radar: AN/TPS-44

Altitude = 30,000 feet

Comment: THE OUTPUT POWER IS 1000 KW. THE POLARIZATION
IS LINEAR AND THE TARGET FLUCTUATION IS SWERLING 1.

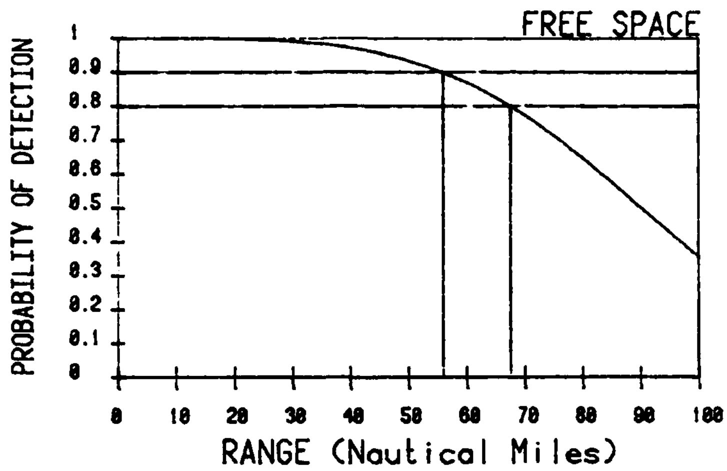
80% , 90% PD Ranges (Free Space) = 67.55, 55.93 nmi

These data were calculated on 120381



80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 60.70, 59.80, 57.37, 56.59 nmi
90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 42.24, 41.38, 38.37, 37.76 nmi

Figure 4.14. Calculated TPS-44 Detection Performance, 30,000 ft Altitude.



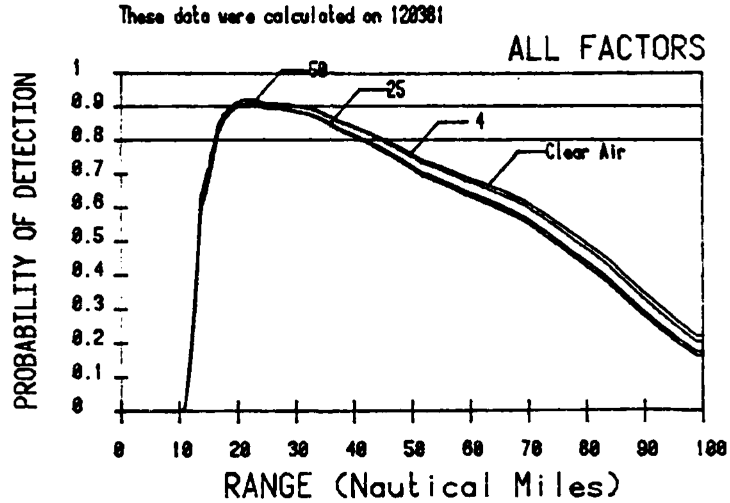
Radar: AN/TPS-44

Altitude = 40,000 feet

Comment: THE OUTPUT POWER IS 1000 KW. THE POLARIZATION
IS LINEAR AND THE TARGET FLUCTUATION IS SWERLING 1.

80% , 90% PD Ranges (Free Space) = 67.55, 55.93 nmi

These data were calculated on 120381



80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 45.47, 44.70, 42.17, 41.30 nmi
90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 31.30, 30.54, 24.51, 24.09 nmi

Figure 4.15. Calculated TPS-44 Detection Performance, 40,000 ft Altitude.

and 54.54 nautical miles. Detection performance in rain is essentially the same as in clear air. However, the TPS-44 will have numerous clutter alarms due to its lack of rain rejection capability. The close spacing of all detection curves for the other aircraft altitudes investigated must be tempered by this realization.

At a 10,000 ft aircraft altitude, there is a multipath interference peak at 100 nautical miles and a null at 96 nautical miles. Detection ranges are all approximately 52 and 48 nautical miles. At 20,000 ft altitude, the detection ranges are all approximately 60 and 50 nautical miles, reflecting the antenna gain pattern.

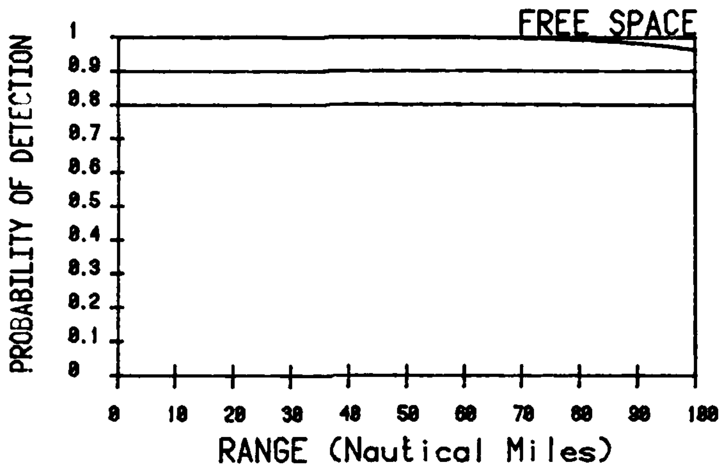
At 30,000 ft aircraft altitude, the detection ranges are approximately 59 and 40 nautical miles. Target fallout occurs at approximately 10 nautical miles, due to the antenna beam pattern. At 40,000 ft altitude, the detection ranges are approximately 44 and 30 nautical miles, and fallout occurs at approximately 18 nautical miles.

The TPS-65 detection performance was computed for the original MATCALS configuration and three variants: the 100 kW crossed field amplifier (MATCALS), a 50 kW solid state, a 25 kW solid state, and a 12 kW solid state transmitter variant. The polarization employed is linear only, and a Swerling 3 target model is appropriate for two frequency operation. A rain filter is used in a range gated fashion, in addition to the MTI filtering employed by this radar and all other radars investigated. All figures depicting TPS-65 detection performance indicate the equivalent peak power of the compressed pulse length.

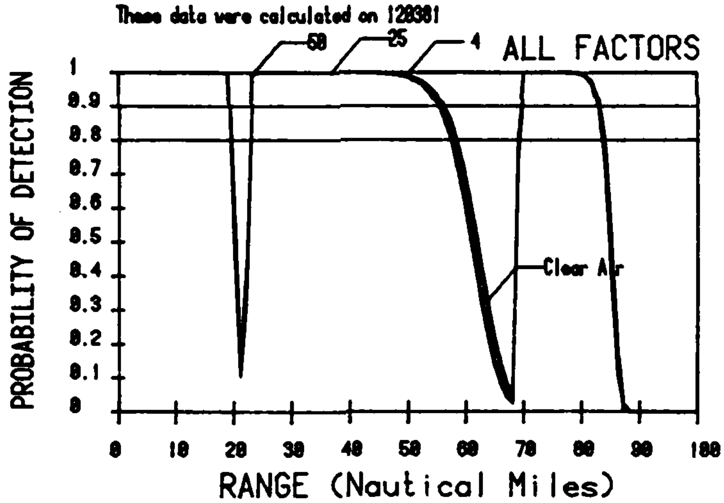
Figures 4.16 through 4.20 depict detection performance for the MATCALS TPS-65. Free space detection range exceeds 100 nautical miles. At 5,000 ft aircraft altitude, there exist two multipath interference peaks at approximately 75 and 40 nautical miles, and two nulls at approximately 68 and 21 nautical miles. The nearest null is relatively narrow in range extent, so that the detection ranges with all factors are essentially 56 and 58 nautical miles.

At 10,000 ft aircraft altitude, the multipath peaks are located at 60 and 100 nautical miles, and the nulls are located at 40 and 95 nautical miles. In addition, the nulls have broadened in range extent, compared with the 5,000 ft altitude case. Initial detection ranges are approximately 78 and 74 nautical miles, but the innermost multipath null is 5 miles in range extent.

At 20,000 ft aircraft altitude, a multipath peak exists at 90 nautical miles, and a broad null 15 miles wide exists around 75 nautical miles. Hard detection ranges are 63.07 and 62.15 nautical miles in clear air and slightly less in rainfall conditions. At 30,000 ft altitude, detection ranges are approximately 84 and 83 nautical miles under all

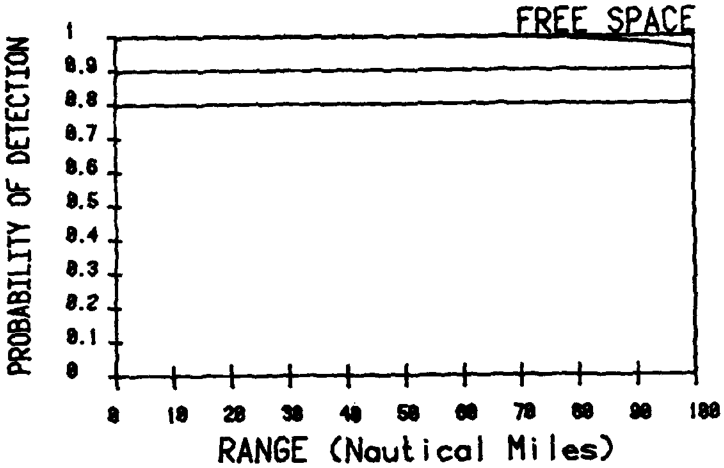


Radar: AN/TPS-65
Altitude = 5,000 feet
Comment: THE OUTPUT POWER IS 3250 KW. THE POLARIZATION
IS LINEAR AND THE TARGET FLUCTUATION IS SWERLING 3.
80% , 90% PD Ranges (Free Space) = 100.00, 100.00 nmi
These data were calculated on 120381



80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 19.46, 19.44, 19.38, 19.38 nmi
90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 19.19, 19.18, 19.15, 19.14 nmi

Figure 4.16. Calculated TPS-65 Detection Performance, 100 kW Power, 5,000 ft Altitude.



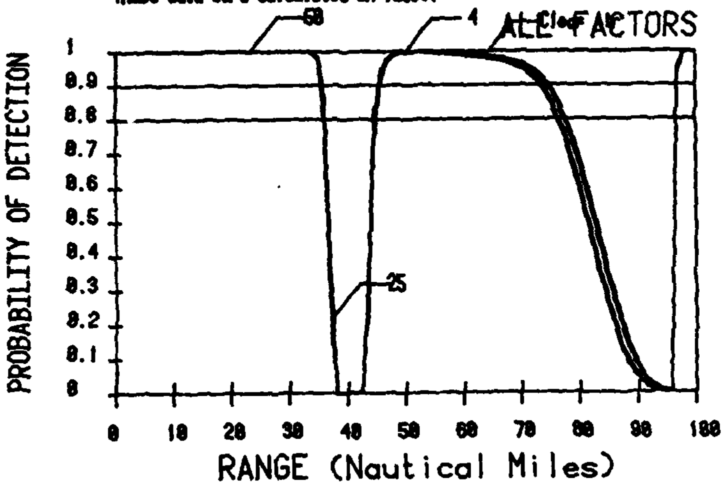
Radar: AN/TPS-65

Altitude = 10,000 feet

Comment: THE OUTPUT POWER IS 3250 KW. THE POLARIZATION
IS LINEAR AND THE TARGET FLUCTUATION IS SWERLING 3.

80% , 90% PD Ranges (Free Space) = 99.99, 99.99 nmi

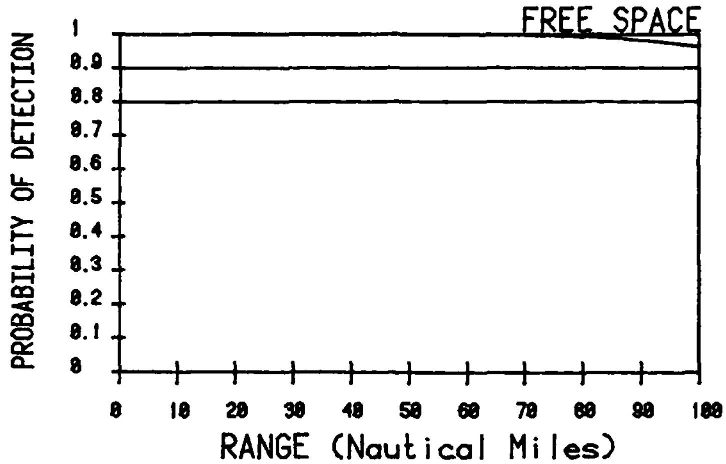
These data were calculated on 120981



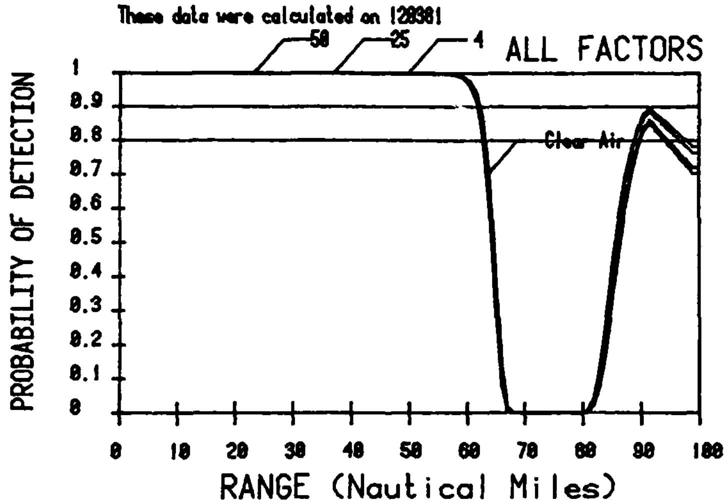
80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 36.12, 36.10, 36.03, 36.01 nmi

90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 35.60, 35.64, 35.46, 35.41 nmi

Figure 4.17. Calculated TPS-65 Detection Performance, 100 kW Power, 10,000 ft Altitude.

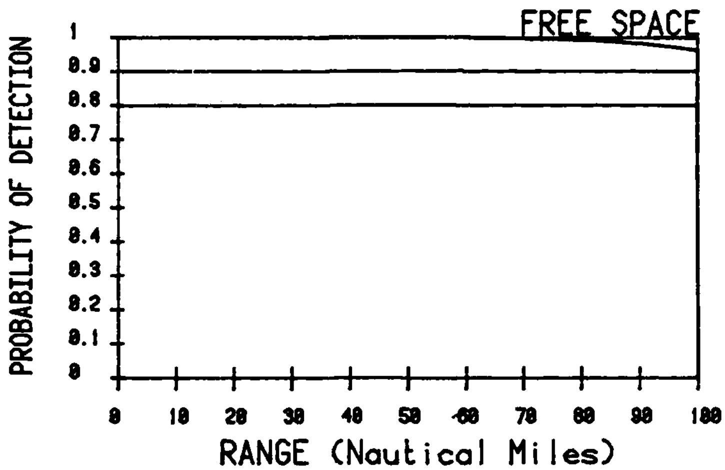


Radar: AN/TPS-65
Altitude = 20,000 feet
Comment: THE OUTPUT POWER IS 3250 KW. THE POLARIZATION IS LINEAR AND THE TARGET FLUCTUATION IS SWERLING 3.
80% , 90% PD Ranges (Free Space) = 99.97, 99.97 nmi
These data were calculated on 120381



80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 63.07, 62.99, 62.76, 62.69 nmi
90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 62.15, 62.05, 61.79, 61.72 nmi

Figure 4.18. Calculated TPS-65 Detection Performance, 100 kW Power, 20,000 ft Altitude.



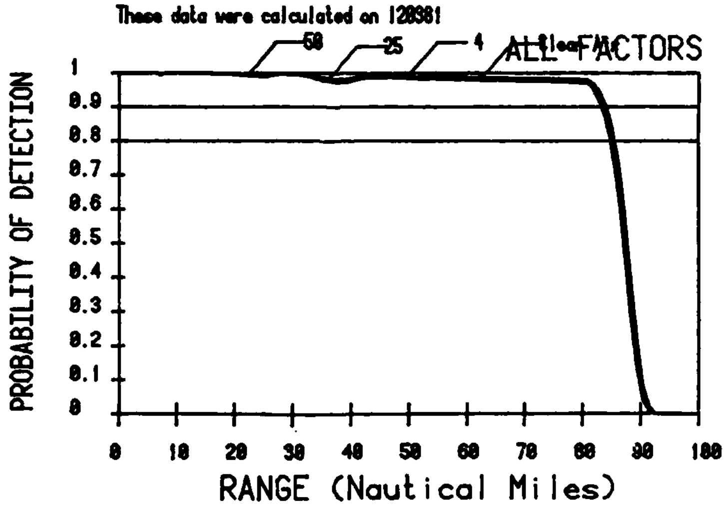
Radar: AN/TPS-65

Altitude = 30,000 feet

Comment: THE OUTPUT POWER IS 3250 KW. THE POLARIZATION
IS LINEAR AND THE TARGET FLUCTUATION IS SWERLING 3.

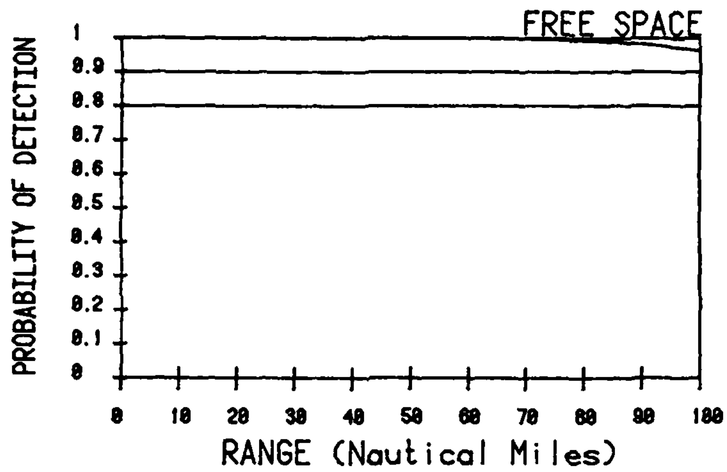
80% , 90% PD Ranges (Free Space) = 99.95, 99.95 nmi

These data were calculated on 120381



80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 85.40, 85.24, 84.84, 84.60 nmi
90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 84.00, 83.80, 83.34, 83.20 nmi

Figure 4.19. Calculated TPS-65 Detection Performance, 100 kW Power, 30,000 ft Altitude.



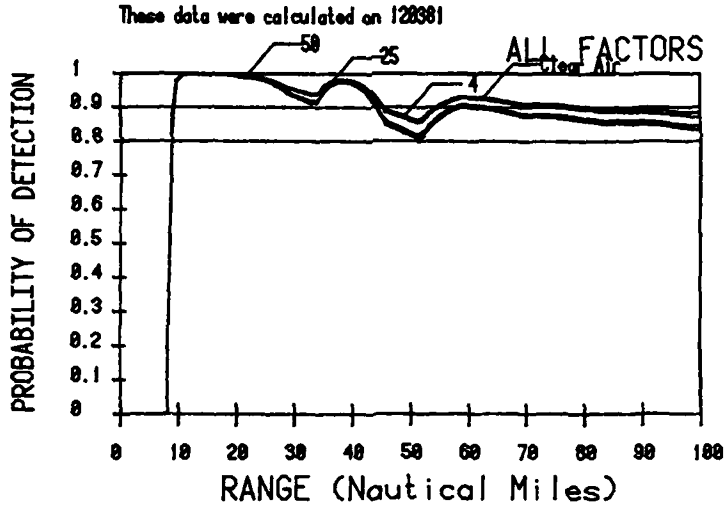
Radar: AN/TPS-65

Altitude = 40,000 feet

Comment: THE OUTPUT POWER IS 3250 KW. THE POLARIZATION IS LINEAR AND THE TARGET FLUCTUATION IS SWERLING 3.

80% , 90% PD Ranges (Free Space) = 99.94, 99.94 nmi

These data were calculated on 120381



80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 98.97, 98.96, 98.93, 98.91 nmi

90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 45.49, 45.25, 44.41, 44.16 nmi

Figure 4.20. Calculated TPS-65 Detection Performance, 100 kW Power, 40,000 ft Altitude.

conditions. At 40,000 ft altitude, detection ranges drop to approximately 45 nautical miles for 90 percent detection, but rise to 99 nautical miles for 80 percent detection. However, aircraft detection fallout occurs at 10 nautical miles.

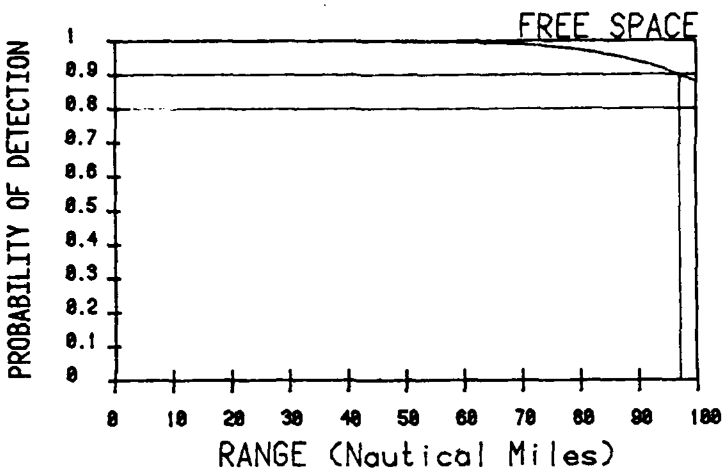
Figures 4.21 through 4.25 depict the target detection performance of a TPS-65 variant with a 50 kW peak power, solid state transmitter. The detection performance shown in these figures reflects a 3 dB loss in S/N ratio relative to the MATCALS TPS-65, which utilizes a 100 kW peak power, crossed field amplifier transmitter. A Swerling 3 target model is justified, as before. Multipath interference peaks and nulls occur again in scenarios defined by MATCALS TPS-65, but are somewhat wider. Free space detection ranges are over 100 and 97.05 nautical miles for 80 and 90 percent detection, respectively.

At 5,000 ft altitude, detection ranges are approximately 56 and 52 nautical miles, under all conditions. At 10,000 ft altitude, detection ranges are 72 and 68 nautical miles. Solid detection ranges at 20,000 ft altitude are 62 and 61 nautical miles. At 30,000 ft altitude they are 83 and 81 nautical miles, and at 40,000 ft they are essentially 42 and 28 nautical miles. At the latter two aircraft altitudes, antenna pattern effects are apparent, and at the 40,000 ft altitude, target detection fallout occurs at 10 nautical miles.

Figures 4.26 through 4.30 depict the target detection performance computed for a TPS-65 variant with a 25 kW peak power, solid state transmitter. As would be expected, multipath peaks and nulls are somewhat wider than that of the previous variant. Free space detection ranges are 90.41 and 80.77 nautical miles, with a Swerling 3 target model, for 80 percent and 90 percent detection, respectively.

At 5,000 ft aircraft altitude, detection ranges are approximately 51 and 49 nautical miles, except for a sharp multipath null at approximately 21 nautical miles. As before, detection in rainfall conditions is not significantly degraded from that in clear air due to the use of a rain filter. At 10,000 ft target altitude, the detection ranges are approximately 65 and 58 nautical miles, but the multipath null centered around 40 nautical miles is 10 miles in range extent.

At 20,000 ft aircraft altitude, detection ranges are approximately 60 and 58 nautical miles, under all conditions. At 30,000 ft target altitude, antenna pattern effects become apparent, and detection ranges are essentially 80 and 30 nautical miles in clear air, but 60 and 30 nautical miles in heavy rain. At 40,000 ft target altitude, detection ranges are only 25 and 20 nautical miles, and target fallout occurs at 10 nautical miles.



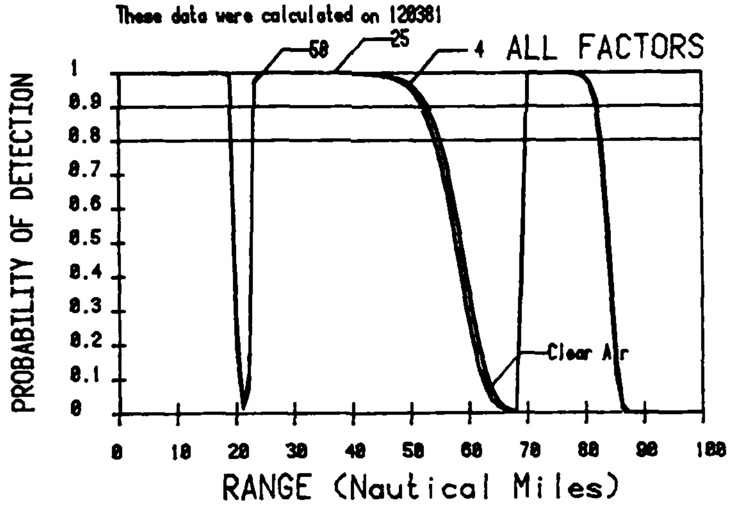
Radar: AN/TPS-65

Altitude = 5,000 feet

Comment: THE OUTPUT POWER IS 1625 KW. THE POLARIZATION
IS LINEAR AND THE TARGET FLUCTUATION IS SWERLING 3.

80% , 90% PD Ranges (Free Space) = 100.00, 97.05 nmi

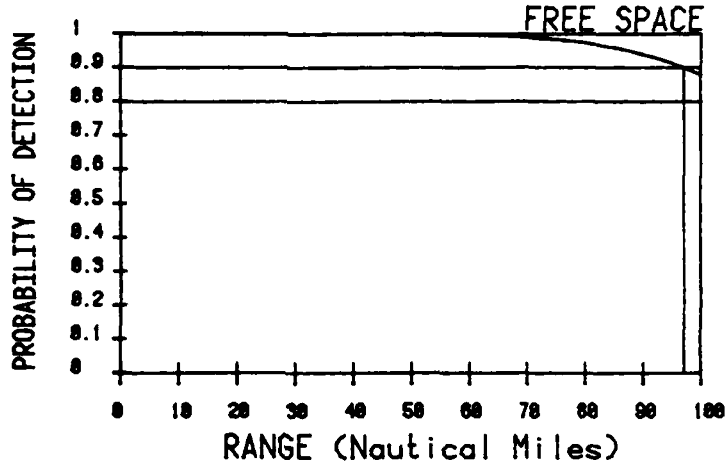
These data were calculated on 120381



80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 19.21, 19.21, 19.19, 19.18 nmi

90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 19.06, 19.06, 19.05, 19.05 nmi

Figure 4.21. Calculated TPS-65 Detection Performance, 50 kW Power, 5,000 ft Altitude.



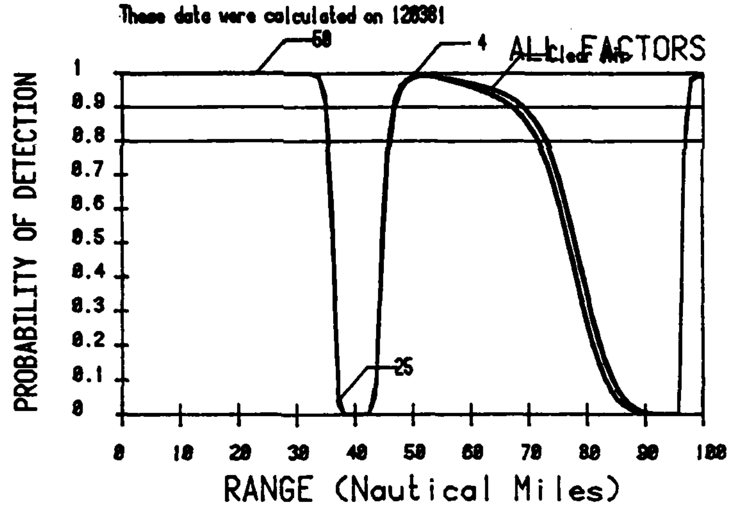
Radar: AN/TPS-65

Altitude = 10,000 feet

Comment: THE OUTPUT POWER IS 1625 KW. THE POLARIZATION IS LINEAR AND THE TARGET FLUCTUATION IS SWERLING 3.

80% , 90% PD Ranges (Free Space) = 99.99, 97.84 nmi

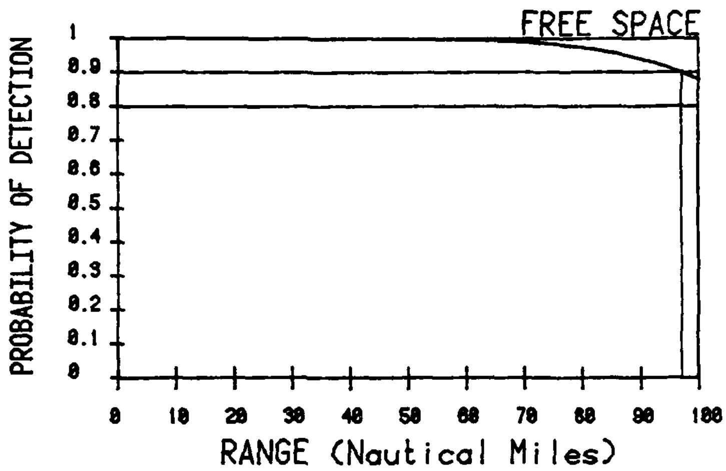
These data were calculated on 120381



80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 35.44, 35.40, 35.28, 35.25 nmi

90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 35.06, 35.05, 34.97, 34.95 nmi

Figure 4.22. Calculated TPS-65 Detection Performance, 50 kW Power, 10,000 ft Altitude.



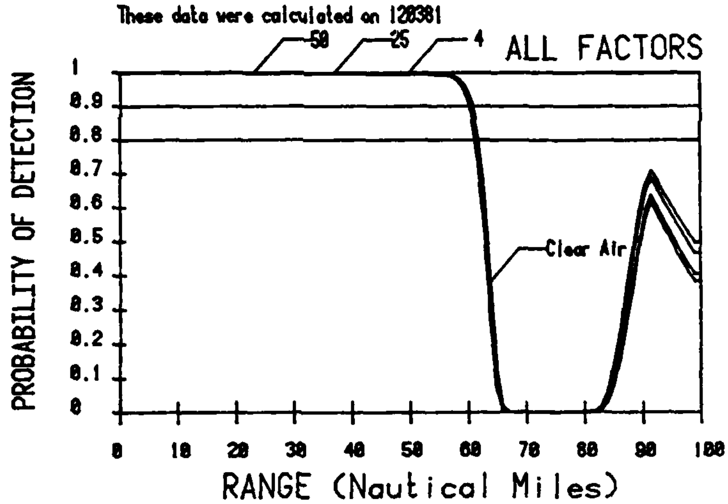
Radar: AN/TPS-65

Altitude = 20,000 feet

Comment: THE OUTPUT POWER IS 1625 KW. THE POLARIZATION IS LINEAR AND THE TARGET FLUCTUATION IS SWERLING 3.

80% , 90% PD Ranges (Free Space) = 99.97, 97.04 nmi

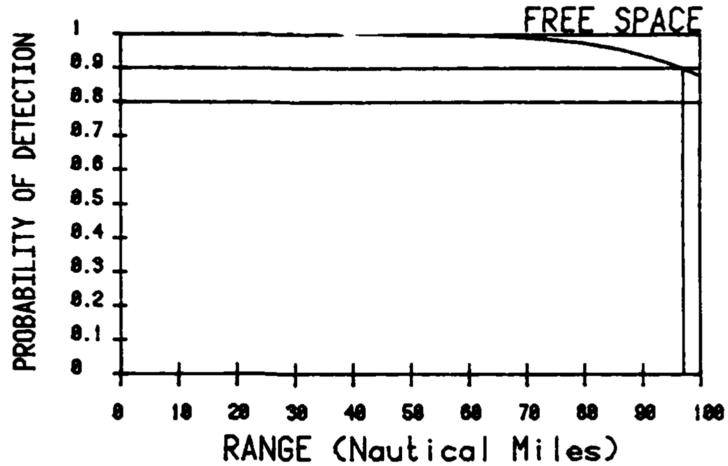
These data were calculated on 120381



80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 61.78, 61.62, 61.28, 61.17 nmi

90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 60.69, 60.61, 60.27, 60.15 nmi

Figure 4.23. Calculated TPS-65 Detection Performance, 50 kW Power, 20,000 ft Altitude.



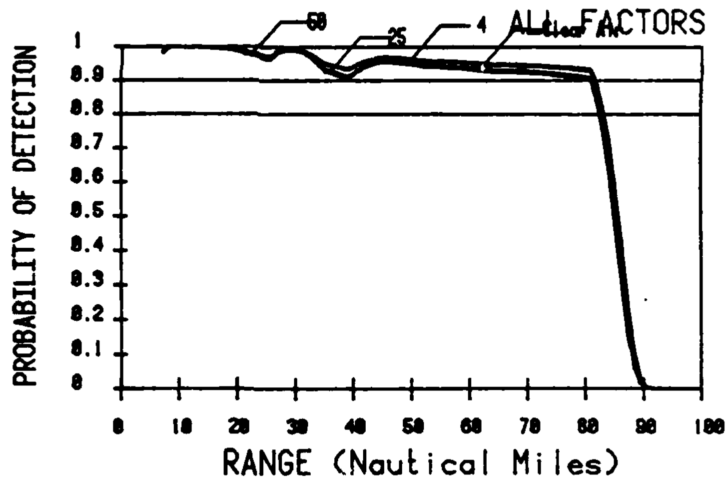
Radar: AN/TPS-65

Altitude = 30,000 feet

Comment: THE OUTPUT POWER IS 1625 KW. THE POLARIZATION IS LINEAR AND THE TARGET FLUCTUATION IS SWERLING 3.

80% , 90% PD Ranges (Free Space) = 99.95, 97.04 nmi

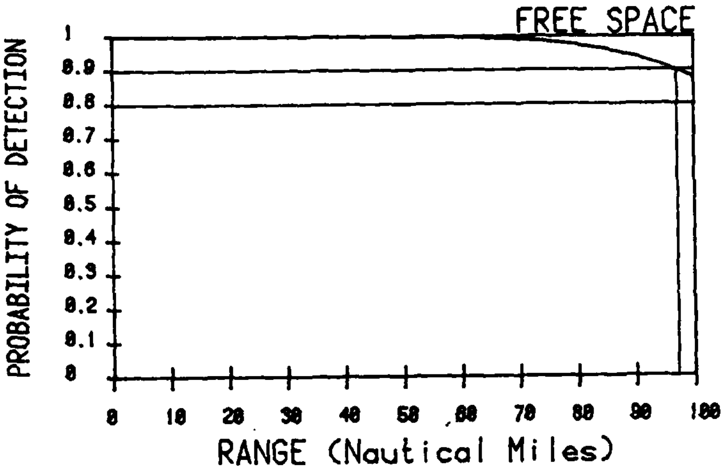
These data were calculated on 120381



80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 83.16, 83.00, 82.53, 82.38 nmi

90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 81.61, 81.40, 80.95, 80.82 nmi

Figure 4.24. Calculated TPS-65 Detection Performance, 50 kW Power, 30,000 ft Altitude.



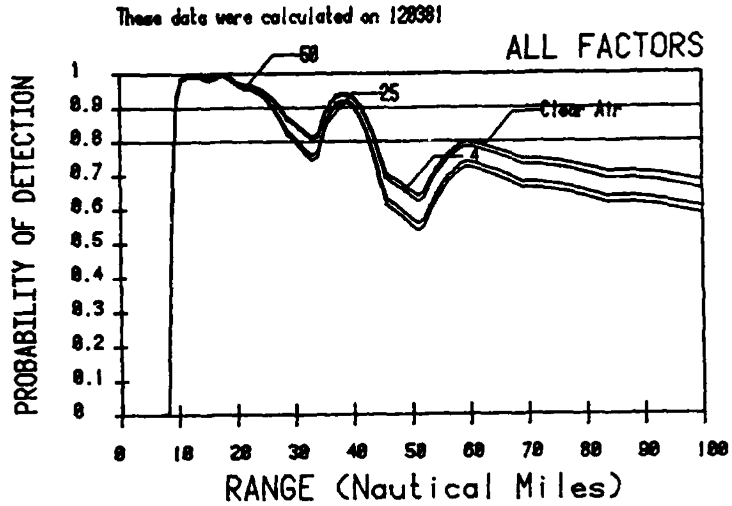
Radar: AN/TPS-65

Altitude = 40,000 feet

Comment: THE OUTPUT POWER IS 1625 KW. THE POLARIZATION IS LINEAR AND THE TARGET FLUCTUATION IS SWERLING 3.

80% , 90% PD Ranges (Free Space) = 99.94, 97.04 nmi

These data were calculated on 120301



80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 44.00, 43.00, 30.85, 30.12 nmi

90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 27.71, 27.40, 26.50, 26.27 nmi

Figure 4.25. Calculated TPS-65 Detection Performance, 50 kW Power, 40,000 ft Altitude.

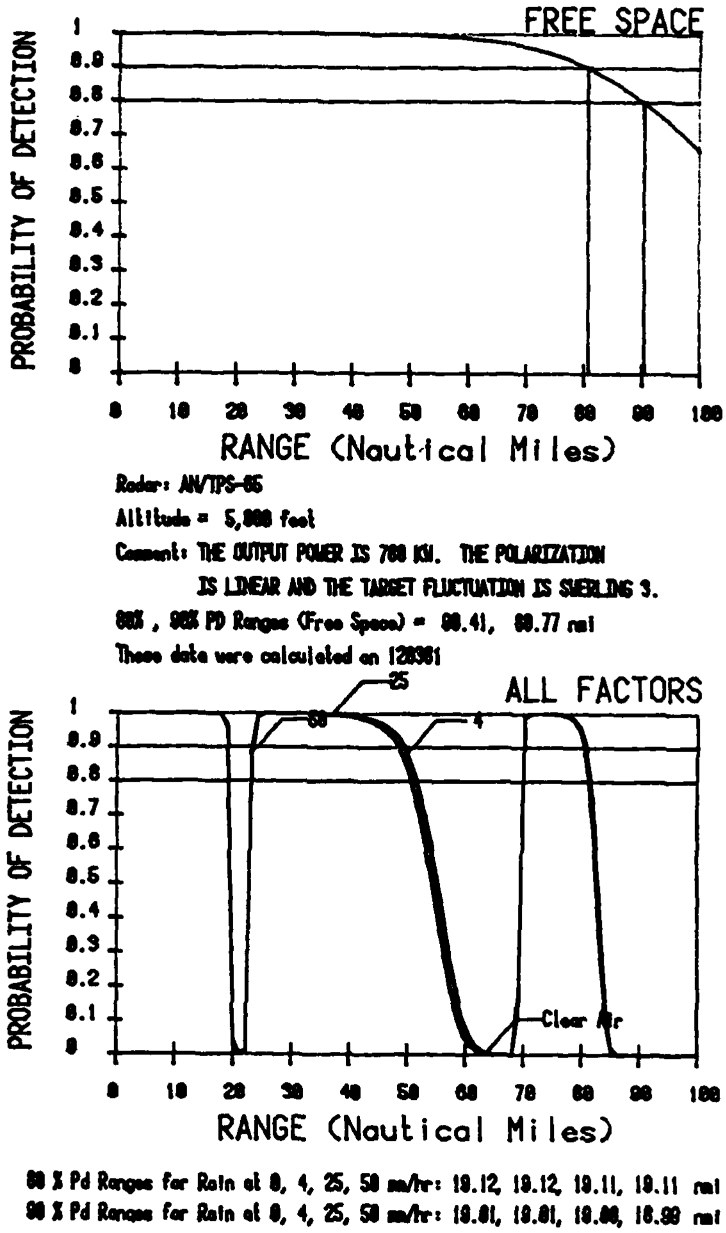
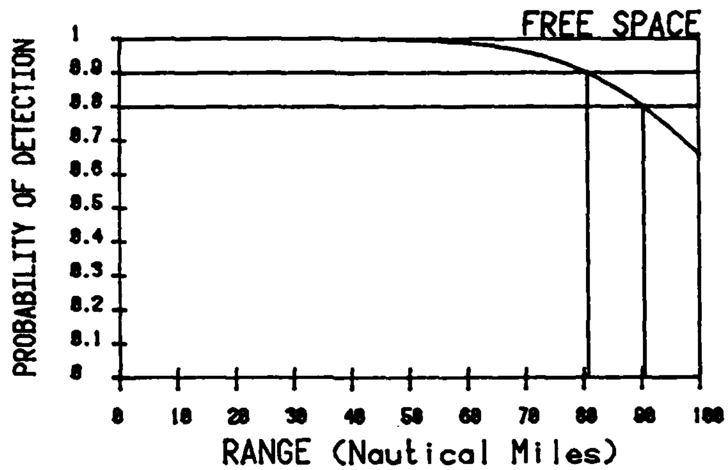


Figure 4.26. Calculated TPS-65 Detection Performance, 25 kW Power, 5,000 ft Altitude.



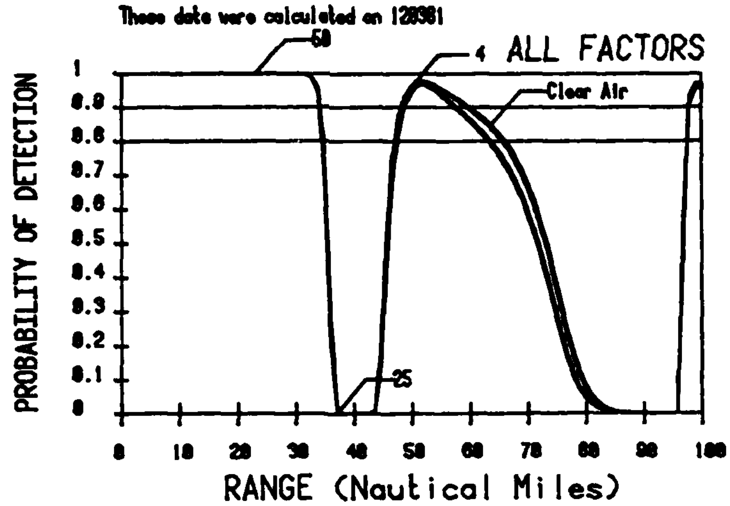
Radar: AN/TPS-65

Altitude = 10,000 feet

Comment: THE OUTPUT POWER IS 700 KW. THE POLARIZATION
IS LINEAR AND THE TARGET FLUCTUATION IS SWERLING 3.

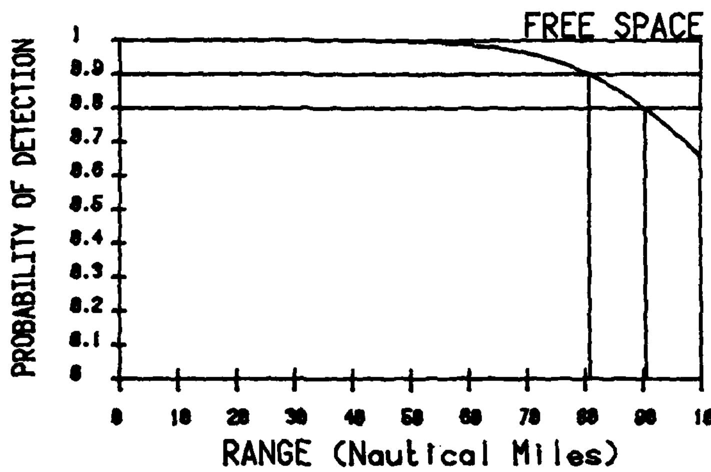
80% , 90% PD Ranges (Free Space) = 90.41, 80.78 nmi

These data were calculated on 120381



80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 34.83, 34.80, 34.63, 34.57 nmi
90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 34.27, 34.24, 34.11, 34.07 nmi

Figure 4.27. Calculated TPS-65 Detection Performance, 25 kW Power, 10,000 ft Altitude.



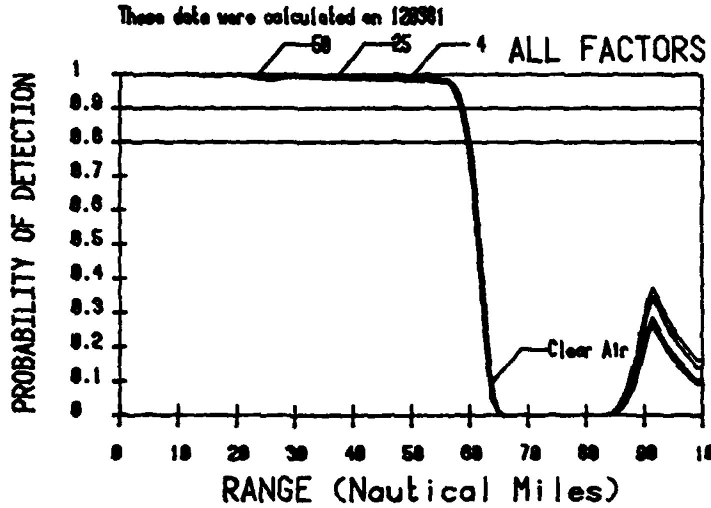
Radar: AN/TPS-65

Altitude = 20,000 feet

Comment: THE OUTPUT POWER IS 700 KW. THE POLARIZATION IS LINEAR AND THE TARGET FLUCTUATION IS SWERLING 3.

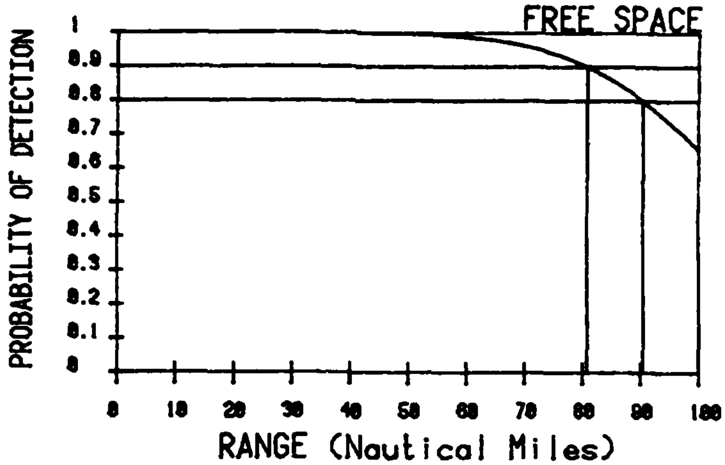
80% , 90% PD Ranges (Free Space) = 90.40, 80.78 nmi

These data were calculated on 120981

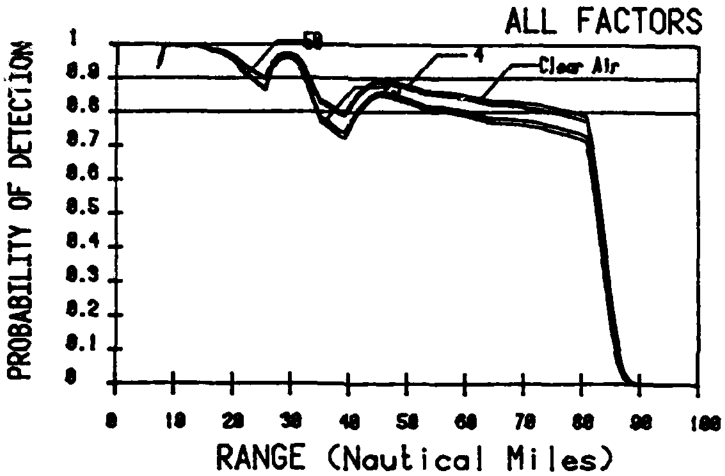


80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 60.02, 59.92, 59.62, 59.53 nmi
90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 58.93, 58.82, 58.52, 58.44 nmi

Figure 4.28. Calculated TPS-65 Detection Performance, 25 kW Power, 20,000 ft Altitude.

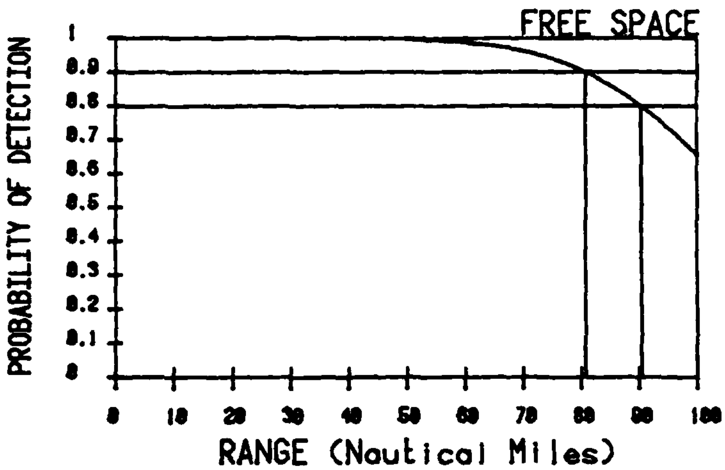


Radar: AN/TPS-65
Altitude = 30,000 feet
Comment: THE OUTPUT POWER IS 700 KW. THE POLARIZATION
IS LINEAR AND THE TARGET FLUCTUATION IS SWERLING 3.
80% , 90% PD Ranges (Free Space) = 90.41, 80.78 nmi
These data were calculated on 120381



80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 30.39, 37.51, 34.67, 34.30 nmi
90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 25.34, 24.90, 23.37, 22.07 nmi

Figure 4.29. Calçulated TPS-65 Detection Performance, 25 kW Power, 30,000 ft Altitude.



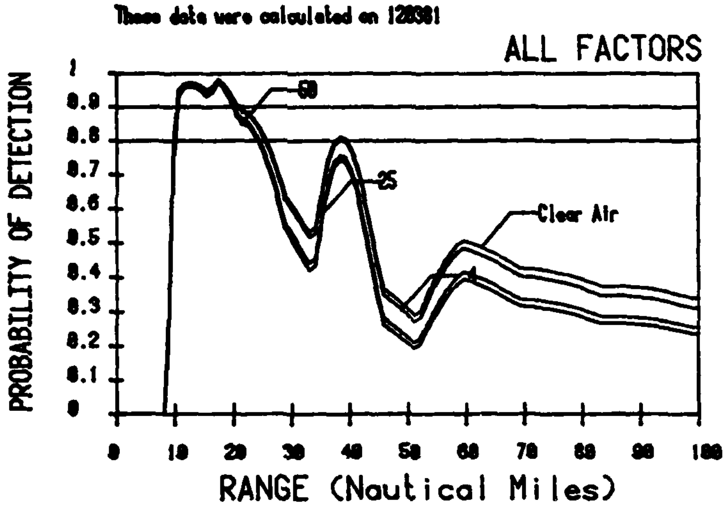
Radar: AN/TPS-65

Altitude = 40,000 feet

Comment: THE OUTPUT POWER IS 700 KW. THE POLARIZATION IS LINEAR AND THE TARGET FLUCTUATION IS SWERLING 3.

80% , 90% PD Ranges (Free Space) = 90.40, 80.78 nmi

These data were calculated on 120381



80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 25.73, 25.50, 24.40, 24.15 nmi
90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 21.02, 20.80, 20.14, 18.91 nmi

Figure 4.30. Calculated TPS-65 Detection Performance, 25 kW Power, 40,000 ft Altitude.

Figures 4.31 through 4.35 depict the target detection performance computed for a TPS-65 variant with a 12 kW peak power, solid state transmitter. The free space detection ranges are 76.01 and 67.92 nautical miles for 80 percent and 90 percent detection, respectively.

The multipath interference effects are similar to those of the other TPS-65 variants, but are wider in range extent. With all factors the 5,000 ft aircraft altitude detection ranges are approximately 48 and 45 nautical miles, with a significant multipath interference null centered around 21 nautical miles. At 10,000 ft aircraft altitude, the null moves to 40 mile range and is over 10 miles in range extent. Significant target detection ranges are 34 and 32 nautical miles.

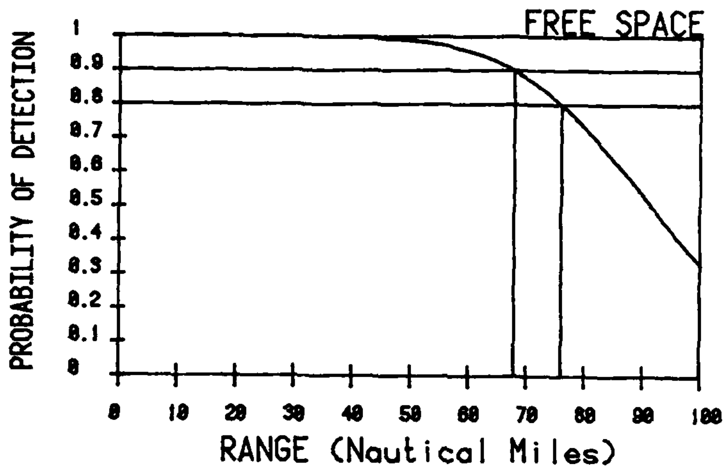
At 20,000 ft aircraft altitude, detection ranges are 58 and 57 nautical miles under all conditions. At 30,000 ft altitude, the detection ranges are essentially 22 and 19 nautical miles, due to power limitations and antenna pattern effects. Target fallout occurs at 10 nautical miles. At 40,000 ft aircraft altitude, the detection range is 19 nautical miles for 80 percent detection, and the 90 percent detection capability is insignificant. Target fallout occurs at 10 nautical miles.

It must again be noted that the MRANGE computer program calculates multipath interference effects at one radar frequency only. For those radar systems that do have the capability of operating two frequencies simultaneously, and summing equivalent signals, the multipath nulls and peaks will be broadened somewhat in range extent, since each will occur at a slightly different range for either frequency. Nulls will tend to "fill in;" that is, the S/N ratio will not be as small as now computed for a single frequency. Likewise, peaks will be decreased somewhat. The net effect on the cited plots of aircraft detection is that the nulls actually experienced will be somewhat less severe than graphically depicted.

4.1.6 ASR INVESTIGATION SUMMARY

The detection range performance of these militarized radars is summarized in Table 4.6. Detection ranges are tabulated for 80 percent and 90 percent probabilities of detection in clear air and three specified rainfall scenarios. In all cases, a false alarm rate of 10^{-6} was utilized in computations of detection probability. Thus, these criteria differ from the MATCALS SOR which specifies a 90 percent detection rate with a 10^{-7} false alarm rate under all specified scenarios through 60 nautical miles.

None of the radar systems investigated met the original MATCALS detection criteria throughout the specified coverage volume. In addition, none met a relaxed set of



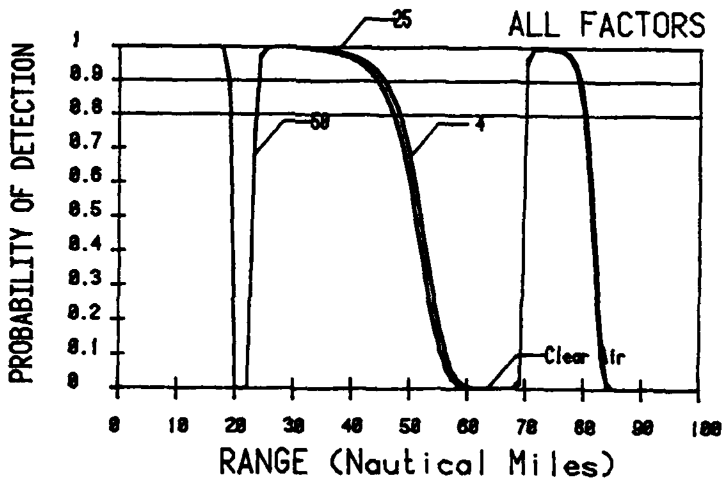
Radar: AN/TPS-65

Altitude = 5,000 feet

Comment: THE OUTPUT POWER IS 300 KW. THE POLARIZATION IS LINEAR AND THE TARGET FLUCTUATION IS SWERLING 3.

80% , 90% PD Ranges (Free Space) = 76.01, 67.92 nmi

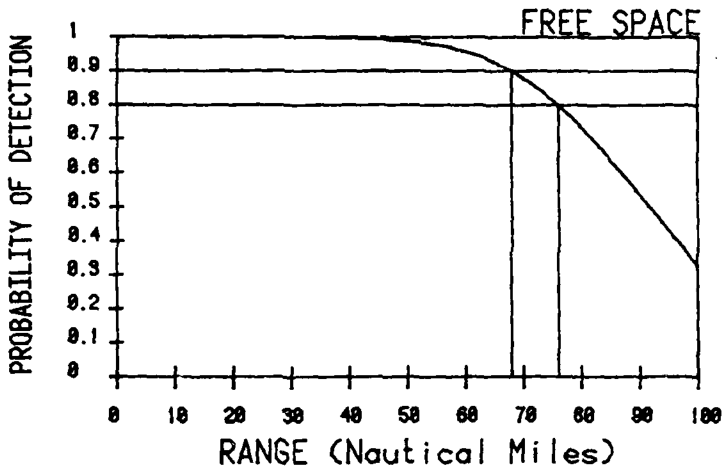
These data were calculated on 120381



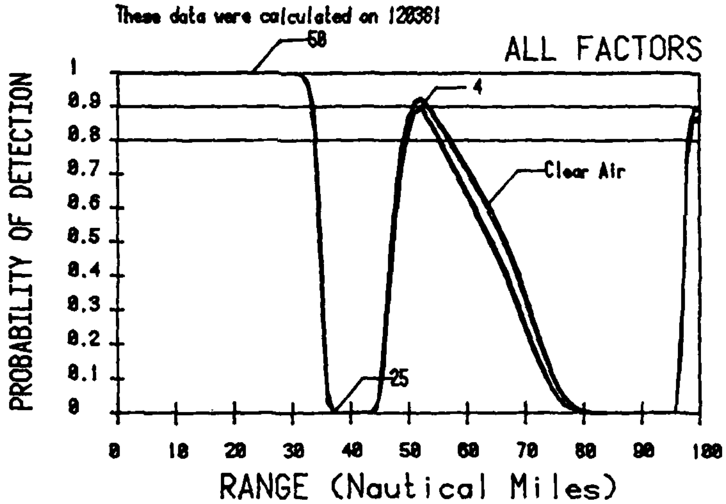
80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 19.04, 19.04, 19.01, 19.00 nmi

90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 18.88, 18.84, 18.67, 18.60 nmi

Figure 4.31. Calculated TPS-65 Detection Performance, 12 kW Power, 5,000 ft Altitude.

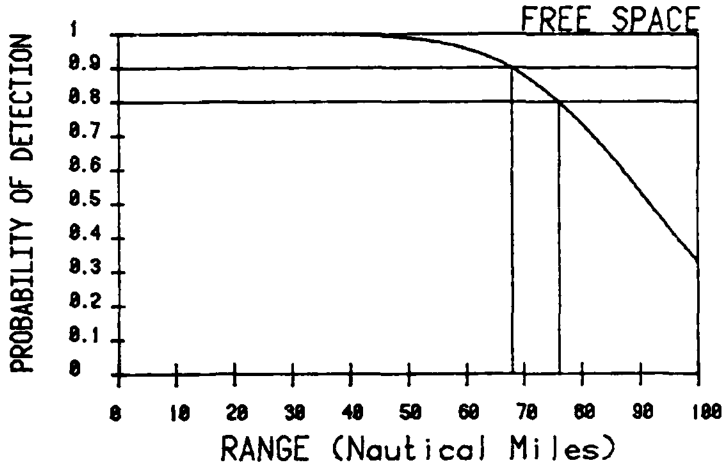


Radar: AN/TPS-65
Altitude = 10,000 feet
Comment: THE OUTPUT POWER IS 390 KW. THE POLARIZATION
IS LINEAR AND THE TARGET FLUCTUATION IS SWERLING 3.
80% , 90% PD Ranges (Free Space) = 76.82, 67.93 nmi
These data were calculated on 120381



80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 34.10, 34.07, 33.96, 33.93 nmi
90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 33.60, 33.54, 33.32, 33.27 nmi

Figure 4.32. Calculated TPS-65 Detection Performance, 12 kW Power, 10,000 ft Altitude.



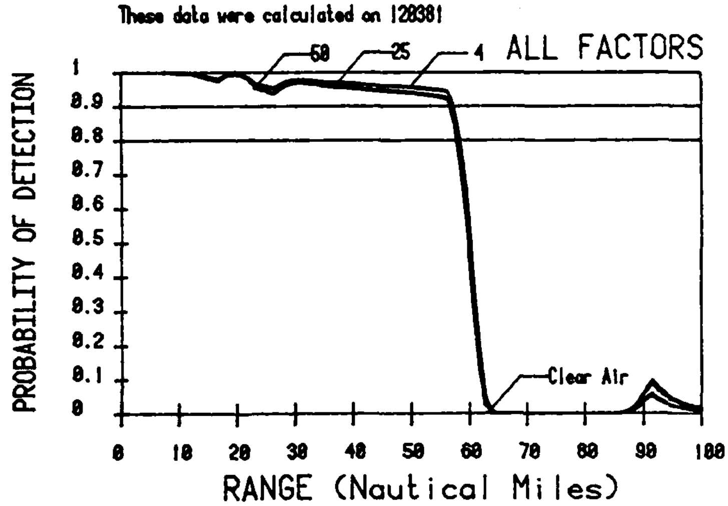
Radar: AN/TPS-65

Altitude = 20,000 feet

Comment: THE OUTPUT POWER IS 390 KW. THE POLARIZATION IS LINEAR AND THE TARGET FLUCTUATION IS SWERLING 3.

80% , 90% PD Ranges (Free Space) = 76.02, 67.93 nmi

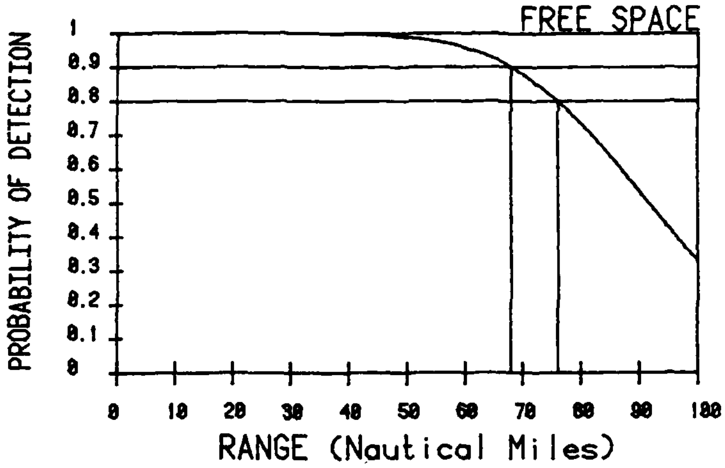
These data were calculated on 120381



80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 58.41, 58.29, 57.89, 57.78 nmi

90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 57.24, 57.10, 56.69, 56.58 nmi

Figure 4.33. Calculated TPS-65 Detection Performance, 12 kW Power, 20,000 ft Altitude.



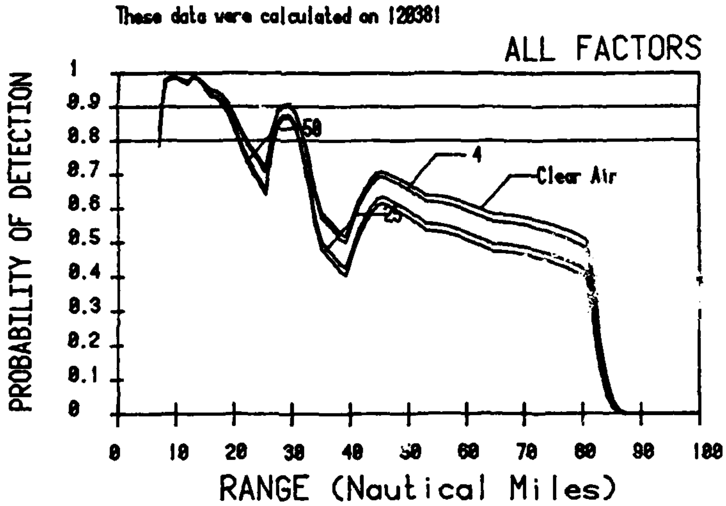
Radar: AN/TPS-65

Altitude = 30,000 feet

Comment: THE OUTPUT POWER IS 390 KW. THE POLARIZATION IS LINEAR AND THE TARGET FLUCTUATION IS SWERLING 3.

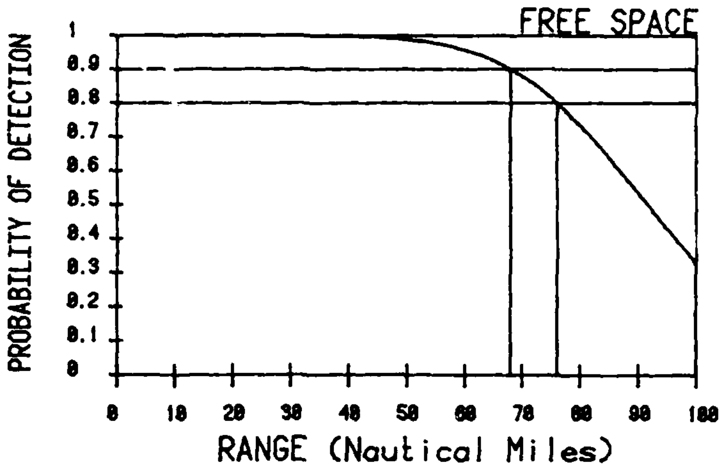
80% , 90% PD Ranges (Free Space) = 76.01, 67.93 nmi

These data were calculated on 120381



80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 22.26, 22.01, 21.08, 20.62 nmi
90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 19.45, 19.32, 18.61, 18.30 nmi

Figure 4.34. Calculated TPS-65 Detection Performance, 12 kW Power, 30,000 ft Altitude.



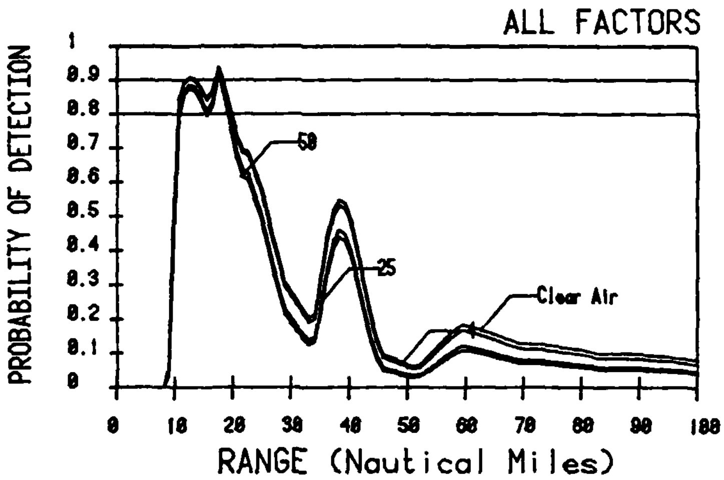
Radar: AN/TPS-65

Altitude = 40,000 feet

Comment: THE OUTPUT POWER IS 390 KW. THE POLARIZATION IS LINEAR AND THE TARGET FLUCTUATION IS SWERLING 3.

80% , 90% PD Ranges (Free Space) = 76.02, 67.92 nmi

These data were calculated on 120381



80 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 19.71, 19.60, 19.19, 15.29 nmi

90 % Pd Ranges for Rain at 0, 4, 25, 50 mm/hr: 13.65, 13.50, 17.86, 17.74 nmi

4.35. Calculated TPS-65 Detection Performance, 12 kW Power, 40,000 ft Altitude.

TABLE 4.6
RADAR MODELING RESULTS SUMMARY

Detection Range

Radar	Aircraft Altitude (ft)	Clear Air 0.8 P_d (nmi)	Clear Air 0.9 P_d	4 mm/hr. 0.8P_d (nmi)	4 mm/hr. 0.9P_d	25 mm/hr. 0.8 P_d (nmi)	25 mm/hr. 0.9 P_d	50 mm/hr 0.8P_d (nmi)	50 mm/hr 0.9 P_d
GPN-24	5,000	44	38	33	29	32	28	31	27
	10,000	52	45	38	31	36	29	35	28
	20,000	54	40	31	10	21	10	11	10
	30,000	46	15	14	12	13	--	13	--
	40,000	20	17	--	--	--	--	--	--
TPN-24	5,000	47	44	36	35	36	33	35	33
	10,000	58	54	43	39	42	38	41	37
	20,000	65	55	28	14	27	14	26	14
	30,000	42	22	14	--	14	--	14	--
	40,000	20	19	--	--	--	--	--	--
TPS-44	5,000	60	55	59	54	58	54	58	53
	10,000	54	49	54	49	53	48	53	48
	20,000	63	53	62	52	60	50	60	50
	30,000	61	42	60	41	57	38	57	38
	40,000	45	31	45	31	42	25	41	25
TPS	5,000 *	58	56	58	56	57	55	57	55
(100 kW)	10,000 **	77	74	77	74	76	73	76	73
	20,000	63	62	63	62	63	62	63	62
	30,000	85	84	85	84	85	83	85	83
	40,000	99	45	99	45	99	44	99	44

* Multipath interference null be partially filled with dual frequencies

** Multipath interference null extent precludes sufficient filling with dual frequencies

TABLE 4.6
RADAR MODELING RESULTS SUMMARY
(continued)

Radar	Aircraft Altitude (ft)	Detection Range: Clear Air 0.8 P_d (nmi)	Clear Air 0.9 P_d (nmi)	4 mm/hr. 0.8P_d (nmi)	4 mm/hr. 0.9P_d (nmi)	25 mm/hr. 0.8 P_d (nmi)	25 mm/hr. 0.9 P_d (nmi)	50 mm/hr 0.8P_d (nmi)	50 mm/hr 0.9 P_d (nmi)
TPS-65	5,000 *	55	53	55	53	54	52	54	52
(50 kW)	10,000 **	73	69	73	69	71	67	71	67
	20,000	62	61	62	61	61	60	61	60
	30,000	83	82	83	82	83	81	82	81
	40,000	44	28	44	28	31	27	30	26
TPS-65	5,000 *	52	49	52	49	50	48	50	48
(25 kW)	10,000 **	66	60	66	60	63	57	63	57
	20,000	61	59	60	59	60	59	60	58
	30,000	38	25	38	25	35	23	34	23
	40,000	26	21	26	21	24	20	24	20
TPS-65	5,000 *	48	45	48	45	47	44	47	44
(12 kW)	10,000 **	57	53	57	53	55	33	55	33
	20,000	58	57	58	57	58	57	58	57
	30,000	22	19	22	19	21	19	20	18
	40,000	20	14	20	14	19	18	19	18

* Multipath interference null be partially filled with dual frequencies

** Multipath interference null extent precludes sufficient filling with dual frequencies

detection criteria, based on 80 percent detection and a 10^{-6} false alarm rate, with the original MATCALS coverage volume.

The GPN-24 radar system demonstrates an aircraft detection range of 45 to 50 nautical miles in clear air and of 30 to 35 nautical miles in rain. The use of circular polarization to reject rain alarms decreases the aircraft detection range as indicated. Detection performance was computed using only for the GPN-24 radiating (lower) antenna beam. High elevation coverage will be better than indicated, since a receive only (upper) antenna beam is used. However, the maximum detection range conclusions are the same as indicated. The GPN-24 would also require design modifications to meet the required MATCALS assembly time criteria.

The TPN-24 radar system demonstrates an aircraft detection range of 45 to 65 nautical miles in clear air and of 25 to 40 nautical miles in rain. The use of circular polarization to reject rain alarms decreases the aircraft detection range as indicated. The coverage volume is essentially limited to aircraft altitudes under 20,000 ft, using only the transmitting (lower) antenna beam pattern.

The TPS-44 radar system demonstrates an aircraft detection range of 45 to 60 nautical miles in clear air and of 40 to 55 miles in rain. However, no rain rejection capability is available, so that detection performance in rainfall conditions is compromised. The TPS-44 is configured as a highly deploybl e system, but is limited to 30 degree elevation coverage.

The CFA (MATCALS) TPS-65 radar system demonstrates an aircraft detection range of 55 to 100 nautical miles in clear air and of 55 to 100 nautical miles in rain. However, severe multipath interference nulls will be experienced under 10,000 ft aircraft altitudes. When two frequency operation is utilized, some null filling will take place, but the farther range null will still significantly degrade detection performance. The generic TPS-65 radar "family" is the only radar of those investigated with the required 0.5 to 40 degree elevation coverage.

The TPS-65 radar system has also been proposed in a solid-state transmitter form. The 50 kW variant demonstrates an aircraft detection range of 45 to 80 nautical miles in clear air and 30 to 80 nautical miles in rain. The 25 kW variant demonstrates an aircraft detection range of 25 to 65 nautical miles in clear air and of 25 to 65 nautical miles in rain. The 12 kW variant demonstrates an aircraft detection range of 20 to 55 nautical miles under all conditions. However, all of these TPS-65 variants are subject to the multipath interference effects previously noted for the MATCALS TPS-65. Target fall-out will take place for a significant period of time around 40 nautical miles range.

The conclusions of this ASR investigation are summarized:

1. No radar investigated meets current MATCALS aircraft detection criteria throughout the specified coverage volume.
2. A suggested alternative set of detection criteria includes an 80 percent probability of detection for a 10^{-6} false alarm rate within the 60 nautical mile range coverage volume, from 1 to 30 degrees in elevation and with a 30,000 ft ceiling.
3. For these alternative criteria, the 50 kW and 100 kW variants of the TPS-65 are the only radar systems having (nearly) adequate detection performance.
4. The TPS-65 system will be susceptible to loss of aircraft detection at 40 nautical miles due to multipath interference.
5. The GPN-24 and TPN-24 are severly range limited for the MATCALS application, and the TPS-44 has no rain rejection capability.
6. The solid state, 50 kW peak power, modular transmitter for the TPS-65 variants offers improved reliability over the CFA MATCALS TPS-65, has graceful degradation capability, does not need water cooling, and may qualify for FAA certification without redundancy.

Georgia Tech recommends that the MATCALS ASR include a modular, solid state transmitter, typified by the TPS-65 variants. If the antenna characteristics of the TPS-65 with 50 kW solid state transmitter were modified to mitigate multipath interference susceptibility, that system would be the clear choice of those systems evaluated.

4.2. RADAR BEACON SYSTEM INVESTIGATION

This section deals with the role of the Air Traffic Control Radar Beacon System (ATCRBS) in performing identification-friend-from-foe (IFF) for the MATCALS mission. A review of radar beacon theory is presented before the advantages of ATCRBS are discussed. Next the role of ATCRBS (IFF) as it relates directly to the MATCALS mission is examined. This discussion leads to the review of the task definition performed and the methodology used. Then the ATCRBS baseline requirements are stated and discussed. ATCRBS product information from the various vendors are reviewed, including an evaluation of performance. Performance results are given, and conclusions for applicability to MATCALS are discussed.

4.2.1 BEACON THEORY

In IFF a ground interrogator transmits a pulse pair, which is received and decoded by an airborne transponder. A reply pulse train is transmitted by the transponder back to the ground station, where it is received and decoded. For ATCRBS the interrogation frequency is 1030 MHz and the transponder reply frequency is 1090 MHz. Usually the interrogator antenna rides "piggyback" on an air surveillance radar antenna, but it can be configured separately. Figures 4.36 and 4.37 describe the ATCRBS system. The interrogator transmits three pulses, usually designated P1, P2, and P3. The spacing between interrogation pulse pairs P1 and P3 determines which of four civilian modes (A, B, C, or D) or four military modes (1, 2, 3, or 4) is desired in a particular communication. Mode 3 (same as Mode A) replies include one of 4096 possible identification codes. Mode C replies furnish altitude information in 100 foot increments. Modes B and D are not currently used in the United States. Mode 4 is the secure military mode. Interrogation pulse P2 is used for both side lobe suppression (SLS) and improved sidelobe suppression (ISLS). SLS is used to inhibit replies to sidelobe radiation. In SLS the P1 and P3 pulses are transmitted from the directional antenna, while the P2 pulse is transmitted from an omnidirectional antenna. If the transponder receives a P2 pulse $2 \pm 0.15\ \mu s$ after the P1 pulse and the amplitude of P1 is not more than 9 dB greater than P2, then the transponder is suppressed for $35 \pm 10\ \mu s$. This action occurs only for radiation received outside the main beam. ISLS is used to reduce the number of replies caused by main beam reflections from various ground structures. In ISLS the P1 pulse with half the amplitude of the P2 pulse, along with the P2 pulse, are radiated from the omnidirectional antenna. This action suppresses transponders outside the main beam, because main beam energy reflected off a ground structure will arrive at the aircraft after the direct P1, P2 pulse, causing the transponder to be suppressed.

The transponder receives the main beam P1, P3 pulse pair and decodes the interrogation mode by means of the spacing between the pulses. Then the transponder responds accordingly with a coded reply at 1090 MHz. A typical reply consists of a pair of framing pulses with 12 pulses between framing pulses. The reply is received by the ground interrogator/receiver and processed for information retrieval.[1]

1 The azimuthally scanning antenna, the measurement of the time to transponder reply, and the transponder returned altitude information (Mode C) give three dimensional target information to the air traffic control system.

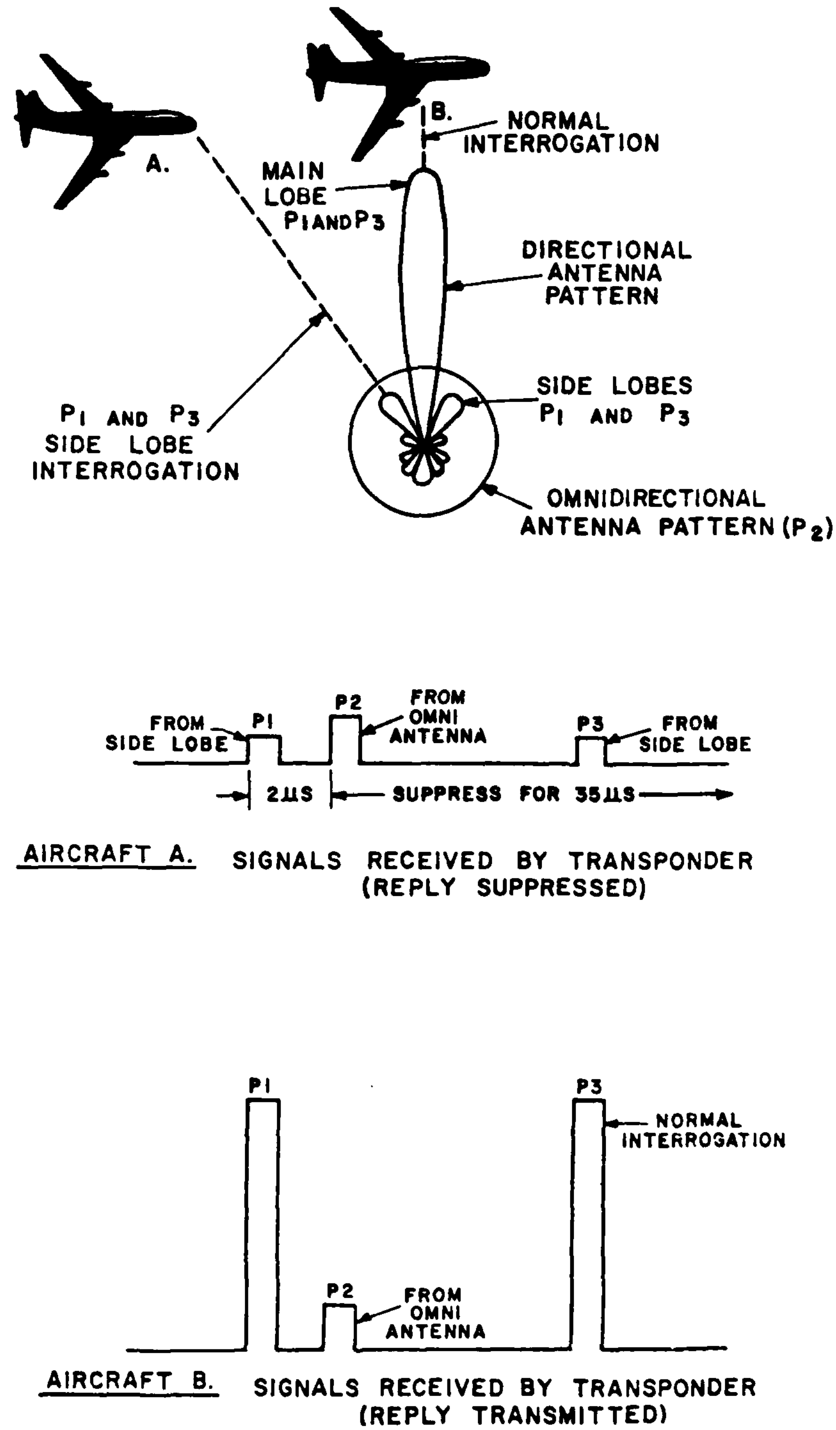


Figure 4.36. Radar Beacon System Radiation Pattern and Sidelobe Supression.

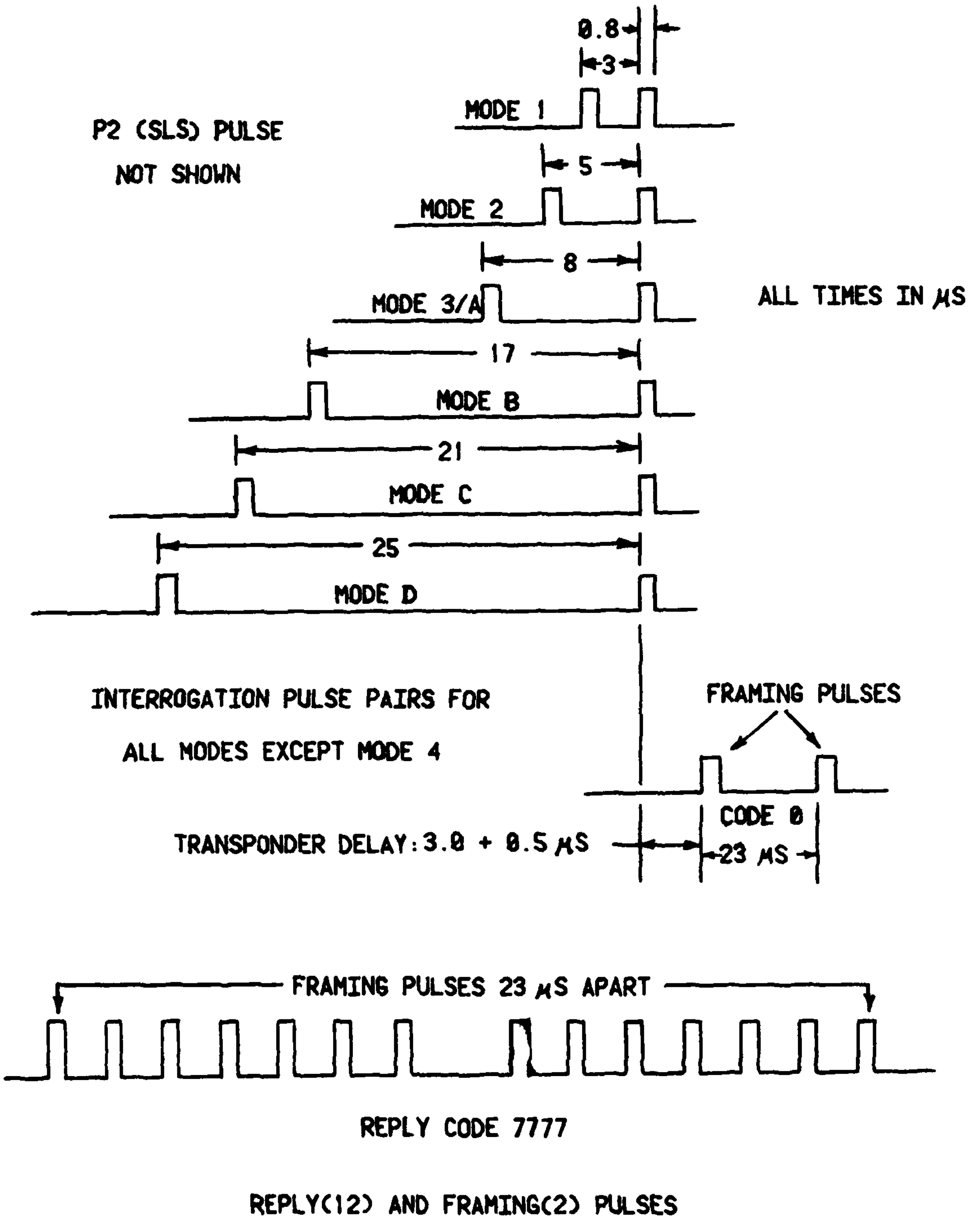


Figure 4.37. Radar Beacon System Transmission Modes and Reply Codes.

The ATCRBS system provides many operational advantages over conventional radar. There is no loss of return signal due to smaller aircraft size. Since the aircraft transponder transmits its own reply, the power received on the ground is inversely proportional to range squared (R^2) instead of the two-way R^4 loss for radar. Ground clutter and weather returns present no problems since the transmitting and reply frequencies are different. Transmission coding in both interrogation and reply provides discrete target identification and altitude reporting. Included in ATCRBS is the capability for the cryptographic aircraft identification (Mode 4) for military applications.

4.2.2 ROLE OF ATCRBS IN MATCALS

IFF performance is critical to the MATCALS mission. Specific Operation Requirement (SOR) 34-22 states that "IFF Mode 3 (ATCRBS) and MODE C (automatic altitude reporting) responses will be the preferred correlation criteria for automatic air traffic control within the terminal area...." This criterion exploits the advantages of IFF over airport surveillance radar (ASR), described in the previous subsection. The main advantages are target identification (including Mode 4), three dimensional information on position, R^2 (range squared) loss in signal strength (instead of R^4 loss), and elimination of weather return problems. The ASR, however, generally gives better performance in azimuth and range accuracy and resolution measurement.[2]

Another disadvantage of ATCRBS is the requirement for a cooperative target. Thus if an aircraft's transponder were inoperative, either from battle damage or technical failure, ATCRBS could provide no information on that target. The same would be true for an enemy aircraft without an operating transponder, although the coverage area for MATCALS is assumed to be militarily secure. In these cases ASR information would be essential in target detection. .

The ATCRBS and ASR systems are complementary. Virtually complete air space coverage can be achieved with the ATCRBS providing three dimensional information on

2 The azimuthal error in ATCRBS is caused by the runlength of the target, which is the number of beacon replies during a given antenna scan. Since this runlength is generally more than ten and may be discontinuous, and since the antenna beam width is somewhat large (3^o), the azimuthal resolution will be several degrees at best. The main source of range error is the inaccuracy in the transponder reply. The transponder replies $3 \pm 0.5\ \mu s$ after the P3 pulse. This $\pm 0.5\ \mu s$ delay error corresponds to a 500 ft range error. These two errors are significantly reduced in the Discrete Address Beacon System (DABS), which is discussed in a following section.

most targets and the ASR providing two dimensional information on targets missed by ATCRBS.

4.2.3 TASK METHODOLOGY

The task concerning ATCRBS' role in MATCALS was fourfold: establish ATCRBS baseline requirements, accumulate vendor product information on applicable off-the-shelf equipment, evaluate the product information on applicable off-the-shelf equipment, and evaluate the product performance.

Establishing ATCRBS baseline requirements involved first reviewing MATCALS requirements (SOR 34-22). This review led to the acquisition of various FAA documents. Combining these inputs with discussions with MATCALS project office personnel resulted in the generation of ATCRBS baseline requirements.

Accumulating vendor product information began with contacting manufacturers of beacon equipment. The FAA was also contacted for identification of additional vendors. All of these companies do not necessarily manufacture a complete line of equipment (antenna, interrogator, and target extractor). Asking these companies for the "missing link" to their own line product led to still other vendors and products. After the initial contact was made with each vendor, usually several interations of correspondence were required to acquire all the information needed for the ATCRBS performance evaluation process.

Evaluating product performance started with division of the ATCRBS hardware into three categories: the antenna, the interrogator, and the target extractor. The important factors for each category of hardware were then identified. A weight was given each factor, based on the relative importance of that factor. Each unit was then subjectively scored for each factor. These scores were multiplied by the relative weight and the final score was the sum of these products.

4.2.4 ATCRBS BASELINE REQUIREMENTS

A first-cut baseline for the MATCALS radar beacon system is summarized in Table 4.7. A more complete baseline specification is described in Appendix C of this report, including notes on entry sources at the end. The rainfall rates are not a great impact on the radar beacon system, but were included since these were a part of the ATC baseline requirements. Many of the beacon baseline specifications represent the definition of ATCRBS rather than requirements such as interrogation frequency,

TABLE 4.7

MATCALS Radar Beacon System Baseline Summary

Aircraft Controlled	40 minimum
Aircraft Pass Through	50 minimum
ATC Compatibility	FAA, U. S., and Allied Forces
Available Modes	1, 2, 3/A, B, C, D (4 compatible)
Maximum Range	200 nautical miles
Azimuth Coverage	0-360 degrees
Elevation Coverage	0.5 - 45 degrees
Altitude Coverage	40,000 ft maximum
Rainfall Environment	4mm/hr full coverage 25-50mm/hr limited coverage
Antenna Scan Rate	6-15 rpm, locked to ASR

interrogation modes and spacing, receiver frequency, and receiver bandwidth for selecting an appropriate system. These parameters are not useful for vendor product evaluation since all ATCRBS equipment include these specifications. Other baseline entries, such as range accuracy and maximum range, have established FAA minimum values but are useful for vendor product evaluation, since equipment performance in these areas does vary. Other parameters, such as range resolution and mean-time-between-failures (MTBF), are not included in the baseline requirements, but are used in the evaluation process.

4.2.5 VENDOR INFORMATION

Information was solicited from radar beacon equipment manufacturers regarding the performance parameters of their systems. The companies and their product lines are listed in Table 4.8. As discussed before, the radar beacon system was defined to be three subsystems: the antenna, interrogator, and target extractor. Several companies manufacture all three subsystems, including Bendix, Hazeltine, and Westinghouse.

4.2.5.1 Antenna

The first subsystem to be discussed is the antenna. A summary of ATCRBS antenna manufacturers and their product performance parameters is shown in Table 4.9. Other system parameters, such as environmental operating conditions, were not included in this table since there was no major variation in performance among candidate systems.

The Bendix Very Light Air Traffic Management Equipment (VLATME) antenna is part of a small, lightweight, ground-based, Air Traffic Management System (ATMS). The entire system is composed of the antenna, APX-100 interrogator, and Target Aquisition Groups (TAG), and includes a microprocessor driven, interactive display. The VLATME system was designed for a tactical helicopter support scenario. As such, range performance is limited to 50 km (27 nmi), and the azimuth resolution is 11°. These two parameters of the VLATME system, as presently configured, do not meet the MATCALS mission requirements. Nevertheless, the VLATME system was included in the ATCRBS evaluation process. The VLATME antenna is a 8-by-8 dipole, Butler matrix-fed, cylindrical, electronically scanned array, is the only electronically scanned beacon antenna included in this evauation, and also is the only one currently employing monopulse capabilities. Bendix is currently exploring the possibility of using the UPX-27 interrogator to increase the VLATME's range, and the use of a large antenna to improve azimuth resolution and accuracy.

TABLE 4.8
Summary of Vendor Products

COMPANY	ANTENNA	INTERROGATOR	TARGET EXTRACTOR
Bendix	VLATME	ATCBI-5 VLATME APX-100	- VLATME TAG
Cardion	-	AN/UPX-27	AN/UPA-59 AN/UPA-60 KY-5035/UPX CTE-2
Eaton/AIL	-	AN/TPX-42, TSDA	AN/TPX-42 VSP
Hazeltine	AN/GPA-123 AN/GPA-128	AN/TPX-54	AN/UPA-59B (V2)
Litton	-	-	CV-3682/UPX
Radiation Sys.	1320-14 B(SD) 1320-28 (SD) (1325-14) 1325-28	-	-
Sperry Univac	-	-	I-SRAP I
Teledyne	-	AN/APX-107	-
Texas Inst.	ASA	-	-
Westinghouse	YES	YES	DECU

TABLE 4.9
Antenna Parameters

COMPANY	MODEL	BEAMWIDTH (3DB)	GAIN	MONOPULSE	MAX INPUT POWER	SIZE WXDXH (INCHES)	WEIGHT (LBS)	VERTICAL[1] COVERAGE (DEGREES)	TYPE OMNI	COST (K$)
Bendix	VLATME	18[2]	20 DB	YES	1 KW	11 DIAM 67 HIGH	70	12.5[3]	INTEGRAL	100
Hazeltine	AN/GPA-123 AND AN/GPA-128[4]	4.5	20 DB	NO	2.5 KW	168X15X15	100	50	INTEGRAL	25
Radiation Sys.	1320-14B (SD)	4.5	19 DB	NO	20 KW	164X25X39	202	28	MODEL 1340	20
	1320-28 (SD)	2.4	21 DB	NO	20 KW	328X25X39	400	28	MODEL 1340	32
	1325-14	4.5	19 DB	YES[5]	15 KW	168X18X64	300	28	INTEGRAL	42
	1325-28	2.35	21 DB	YES[5]	15 KW	318X18X64	545	28	INTEGRAL	65
TEXAS INST.	A5A	2.4	21 DB	YES[5]	10 KW	310X X64	550	UNIFORM TO 30	INTEGRAL	80
WESTINGHOUSE	AN/TPS-65	3	29 DB	NO	10 KW	216X X192	NO EXTRA	COSECANT SQUARED	AS-177B (0.5 METER)	NO EXTRA

1 At 3 DB below peak unless otherwise specified
2 18 degrees is the reply zone width
3 12.5 degrees at 3 DB points, beam is squinted above horizon with 6DB point at horizon
4 The 123 and 128 differ in the type of rotary joint
5 The monopulse capability is not usable in the present ATCRBS System, but is designed for future use in DABS

The Hazeltine antennas (AN/GPA-123 and AN/GPA-128) differ only in the type of rotary joint (single vs dual channel, respectively). The Hazeltine antennas are housed in radomes and are the lightest antennas investigated, except for the electronically scanned Bendix antenna. The Hazeltine antennas are also the most tactical of these antennas because of their weight, size, and mounting ride; they "piggyback" on the ASR antenna.

Radiation Systems, Incorporated (RSI) makes two different kinds of antennas, in both a 14-foot and 28-foot width version. Models 1320-14B (14 foot) and 1320-28 (28 foot) are the traditional ATCRBS hogtrough antennas. Models 1325-14 (14 foot) and 1325-28 (28 foot) are designed to have monopulse capability for DABS compatibility. These two monopulse antennas are designed for a sharp underside cutoff in the elevation pattern to reduce ground reflections. Like the Hazeltine and Texas Instruments antennas, the Radiation Systems antennas are designed to ride "piggyback" on the ASR antenna.

The Texas Instruments (TI) A5A (designated A5A for ATCRBS Five Foot Antenna) is also designed with monopulse capability to be used for DABS. However, over one hundred of these antennas have been deployed by the FAA with the ASR-8 systems. The A5A also rides "piggyback" on the ASR antenna. There seems to be no significant major difference in the specifications of the TI A5A and the RSI 1325-28 antennas.

The Westinghouse AN/TPS-65 system has an integral IFF and surveillance radar feed, which eliminates the need for a separate IFF antenna. The ASR antenna is larger, thus giving a higher gain (29 dB) than the other ATCRBS antennas, but the elevation antenna pattern drops off faster. The antenna is a parabolic cylinder fed by dipole radiators. Because of the integral ASR and ATCRBS feed, no extra IFF antenna is required.

4.2.5.2 Interrogator

The interrogator manufacturers and product lines are listed in Table 4.10. The interrogator is probably the most straightforward of the three subsystems in the beacon system. Even so, there is a wide variation in candidate parameters, such as size, weight, and range. The units vary in size from the Bendix ATCBI-5, a large unit currently deployed in the FAA system, to the Teledyne AN/UPX-107, a small unit designed for airborne use. The Mean Time Between Failure (MTBF), Mean time To Restore (MTTR), size, and weight parameters are based on a single channel only. System redundancy and the switchover network are not included in these data.

TABLE 4.10
Interrogator Parameters

COMPANY	MODEL	POWER (WATTS)	RANGE (NMI)	MODES	RECEIVER SENSITIVITY (DBM)	MTBF[1] (HRS)	MTTR[1] (MIN)	SIZE[1,2] WXDXH (INCHES)	WEIGHT[1] (LBS)	COST[3] (K$)
Bendix	ATCBI-5	3200	200	1, 2, 3/A, B, C, D, 4	-87	1000	30	22X22X76	760	120
	VLATME APX-100	400	27	2, 3/A, C	-74	2000	30	3X 3X 5	3	50[4]
Cardion	UPX-27	2000	200	1, 2, 3/A, C, 4[5]	-84	2000	30	11X18X16	57	225
Eaton/AIL	AN/TPX-42A, TSDA	2000	200	1, 2, 3/A, C	-86	5200	45	19X21X21	108	110
Hazeltine	AN/TPX-54	1500	200	1, 2, 3/A, C, 4	-80	2000	15	26X15X 8	56	140
Teledyne	AN/APX-107	1500	160	1, 2, 3/A, C, 4	-83	1500	15	5X16X 8	27	140
Westinghouse		2000	248	1, 2, 3/A, C, 4	-84	6500	12	16X24X30	125	400

1. Based on one channel only
2. Dimensions are rounded to nearest inch
3. Costs are approximate and include redundant configuration with switchover network unless otherwise noted
4. Cost does not include switchover network
5. Optional expansion to include modes B and D is available

Bendix manufactures two units listed in Table 4.10. The first unit is the ATCBI-5, the most recent ATCBI equipment being deployed by the FAA. This system is the largest and most powerful (3200 watts) interrogator identified and also the only one currently having Mode B and Mode D capability. However this mode capability is no real advantage, since these two modes are not currently being used by the United States. The Bendix VLATME APX-100 interrogator is a modified transponder used in ATMS, discussed in the previous secton on antennas. It has low power (400 watts), thus a short range (27 nautical miles) and is not really a viable candidate for MATCALS application.

The Cardion UPX-27 is a small lightweight interrogator currently being used by the Marine Corps. The EATON/AIL AN/TPX-42A Transfer Switching Drawer Assembly (TSDA) is an interrogator which has been configured in many ways, has been around a long time, and does not have Mode 4 capability. The Hazeltine AN/TPX-54 is a fairly new interrogator designed for shipboard, tactical, and traditional IFF usage, with performance comparable to the Cardion UPX-27, except for slightly less power and sensitivity. The Teledyne AN/APX-107 is a very small, lightweight interrogator designed for airborne use, and its power and, thus the range, is somewhat reduced from the other interrogators. Although the AN/APX-107 power (1500 watts) is the same as the Hazeltine AN/TPX-54, the AN/APX-107 range performance is less because its defruiter is limited to 160 nmi. This range can be expanded, however, by adding more memory. The MTBF is 500 hours for airborne use and 1500 hours for ground use. A switchover network would have to be built for the AN/APX-107. Probably the newest interrogator is the solid state IFF unit from Westinghouse. This interrogator is designed to be used with the AN/TPS-43E, AN/TPS-63, and AN/TPS-65 radars. It has the highest reliability of all the interrogators, but is also the most expensive.

4.2.5.3 Target Extractor

The target extractor is responsible for taking the defruited video from the interrogator receiver, extracting the target information, correlating the beacon information with the surveillance radar information (if available), and preparing the information for display on a plan position indicator (PPI) or other display. Other extractor functions include checking the returns for the various alarm codes (7500, 7600, 7700) and sending information to another computer site. Table 4.11 lists the target extractors considered and the companies which produce them. These systems vary greatly in their performance and capabilities. The resolution and accuracy in azimuth is

TABLE 4.11
Target Extractor Parameters

COMPANY	NAME	RESOLUTION RANGE (FT)	RESOLUTION AZ (DEG)	ACCURACY RANGE (FT)	ACCURACY AZ (DEG)	TARGET CAPACITY	MAX RANGE (MILES)	SIZE WXDXH (INCHES)	WEIGHT (LBS)	MTBF (HR)	MTTR (MIN)	CORRELATION WITH RADAR	COST (K$)
Bendix	VLATME TAG	330	11.0	1300	2.0	1	27	14X14X16	40	1000	30	NONE	100
Cardion	AN/UPA-59 AND AN/UPA-60	PPI DEPENDENT		PPI DEPENDENT		1	PPI DEP	6X18X12 10X18X 7	27	2000	30	NONE	20
	KY-5035/UP X	PPI	DEP	PPI	DEP	1	PPI DEP	7X19X15	38	4300	30	NONE	17
	CTE-2	760	3.7	1000	1.0	10000	512	19X19X 7	38	5000	15	NONE	50
Eaton/AIL	AN/TPX-42 VSP	800	4.0	380	0.3	64	200	19X31X12	90	4770	45	NONE	90
Hazeltine	AN/UPA-59B (V2)	800	3.3	1000	0.2	1	200	6X18X12	30	2851	15	NONE	15
Litton	CV-3682/UPX	500	3.6	120	0.2	700	250	19X24X24[1]	550[1]	3000	20	YES	234[1]
Sperry-Univac	I-SRAP I	190	5.3	270	0.1	250	200	19X19X11	100	5427	13	YES	50
Westinghouse	DECU	1000	3.0	250	0.7	64	250	34X16X48[1]	230[1]	4850	60	YES	200[1]

1. Includes radar and beacon processing

greatly dependent on the antenna. The beamwidth was assumed to be 3° for all systems, except the Bendix VLATME. The target capacity is the number of targets for which the extractor can simultaneously furnish information on squawk code, altitude, etc.

The Bendix VLATME TAG (Target Acquisition Group) target extractor has poor azimuth resolution and accuracy, limited range, and limited target capacity. The azimuth deficiency is due to the design of the VLATME antenna. The total target capacity is 102 aircraft, but target data (ID, range, altitude, and azimuth angle) can be displayed for only one target at a time.

Cardian manufactures several target extractors. The AN/UPA-59, AN/UPA-60, and KY-5035/UPX are all small decoders which have limited target capacity (1 target selected by a light gun on a PPI). These capabilities are not sufficient to meet minimum MATCALS requirements. The CTE-2, however, provides a much more powerful capability. It has a processing capability of 10,000 replies per second and a maximum range of 512 nautical miles.

The EATON/AIL AN/TPX-42 Video Signal Processor (VSP) is similar to the CTE-2 in that both produce an 88-bit serial message for each target. Because of memory limitations the in-process capacity of the AN/TPX-42 is restricted to 64 targets per sweep at a PRF up to 450 pulses per second.

The Hazeltine AN/UPA-59B (V2) is an updated, improved version of the AN/UPA-59. However, the target capacity is still one, so the AN/UPA-59B is not applicable for the MATCALS mission.

The Litton L-2100 is a distributed processor which provides automatic target detection and tracking for IFF and pulsed, surveillance radars. This unit has been acquired by the Navy and has the nomenclature CV-3682/UPX. The processing of both IFF and radar allows for correlation of the IFF with radar returns. The size, weight, and cost listed in Table 4.11 include the complete processor (radar and beacon).

The Sperry-Univac I-SRAP I (Sensor International Receiver and Processor) also includes provision for IFF and radar processing and correlation. The beacon information is processed in the Beacon Data Acquisition Subsystem (BDAS), while the radar processing is accomplished in the Radar Data Acquisition Subsystem (RDAS). The I-SRAP is a modified version of the SRAP I which is basically very similar. The SRAP I will be implemented into the FAA ARTS III. The cost shown in Table 4.11 includes only the BDAS, but the RDAS is approximately the same cost, if correlation with radar is desired.

The last target extractor considered is the Westinghouse DECU. It processes both the IFF and radar information. The size, weight, and cost in Table 4.11 include the entire DECU (IFF and radar). The target capacity of the DECU is 64 by specification, although the internal capacity is larger.

4.2.6 EXPLANATION OF EVALUATION FACTORS AND WEIGHTS

To quantify vendor IFF product applicability to MATCALS is a difficult task. Even though the IFF system seems straightforward, the various manufacturers approach the ATCRBS in varying ways, and each system has its own distinct advantages. The selection of a number of parameters to be quantified is difficult. This quantitative evaluation, with the more complete parameter tables in the previous subsections, should provide a useful tool in the selection of an appropriate IFF system for MATCALS. The factors used for evaluation, with their designated relative weighting factor for each of the three IFF subsystems (antenna, interrogator, and target extractor), are listed in Table 4.12. These weights indicate the importance of that factor relative to other factors being considered for that particular subsystem. One example is that the beamwidth of the antenna is deemed three times as important as the type of omnidirectional antenna. Comparisons between different subsystems, such as antennas and interrogators, either for a specific factor or total score are not valid. A particular vendor product was given a rating value between 0 and 5 for each factor, with 5 designating best performance or design. This rating value was multiplied by the appropriate weight, and the sum of these products yielded a total score for that product. The factors considered are discussed below.

The antenna is the simplest of the three subsystems, and it has the fewest number of factors. The beamwidth, gain, and transportability were judged to be of relatively equal importance. The beamwidth of the antenna largely determines the azimuth resolution. The gain is a major factor in the range limitation of the system. Transportability is a critical factor for the MATCALS tactical application. Cost was judged less important than these three, and the type of omnidirectional antenna even less important. Some antennas required no additional external omnidirectional antenna, a situation which was judged to be advantageous for reasons of size, cost, and fewer components.

The interrogator factors and relative weights are more complex than the ones for the antenna. The available modes had a relative weight of 4 because of the requirement for Mode 4 capability. Reliability (relative weight 3) is critical, although the redundancy

TABLE 4.12

Evaluation Factors and Weights

ANTENNA

FACTOR	RELATING WEIGHT
Beamwidth	3
Gain	3
Transportability	3
- Size	
- Weight	
Cost	2
Omni Antenna	1

INTERROGATOR

FACTOR	RELATIVE WEIGHT
Available Modes	4
Reliability	3
- MTBF	
- MTTR	
Transportability	3
- Size	
- Weight	
Power Output	3
Receiver Sensitivity	2
Cost	2

TARGET EXTRACTOR

FACTOR	RELATING WEIGHT
Resolution and Accuracy	4
- Azimuth	
- Range	
Reliability	3
- MTBF	
- MTTR	
Cost	2
Target Capacity	2
Transportability	1
- Size	
- Weight	
Processes and Correlates	1
- Radar Data	

required by the SOR vastly increases overall performance. Transportability (relative weight 3) is essential for tactical operation. This parameter varies greatly in the available systems. The power output (relative weight 3) determines range limits more than receiver sensitivity (relative weight 2), because the downlink (transponder to receiver) generally has greater reserve gain than the uplink (interrogator to transponder). System cost (relative weight 2) varied greatly from vendor to vendor.

The target extractor was probably the most difficult subsystem to establish factors and relative weights for, as well as to evaluate. The resolution and accuracy of the target extractor (relative weight 4) was judged most important, since the target location is the most significant IFF system output. Reliability (relative weight 3) is critical since there is no redundancy in the target extractor subsystem. System cost (relative weight 3), again, varies substantially as does the target capacity (relative weight 2). Some of the units do not meet the MATCALS requirement for target capacity. The units do not vary greatly in transportability (relative weight 1), except for the weight of the Litton CV-3682/UPX. A relative weight of 1 was given to processing and correlating radar data, which might be underestimated in importance.

The factors listed for the three subsystems are certainly not the only factors which could have been considered. In addition the weights and scores are not absolute. Even so, the evaluation procedure should be of use in screening some of the units.

4.2.7 RESULTS

The vendor products were evaluated for MATCALS application using information summarized in Tables 4.9 through 4.11 along with the evaluation procedure discussed in subsection 4.2.6. A total score for each unit was determined by multiplying the rating for each factor by the relative weight for that factor, then summing the products for all factors for that unit. The scoring results for the antenna, interrogator, and target extractor subsystems are discussed in the following subsections.

4.2.7.1 Antenna Results

The antenna evaluation results are given in Table 4.13. Because smaller beamwidths are desirable for target resolution, antennas with beamwidths of 2.4^{o} were scored 5, beamwidths of 4.5^{o} scored 3, and 3^{o} beamwidth scored 4. The VLATME beamwidth (18^{o}) scored 1. The gain scores were 2 (for 19 dB), 3 (for 20 dB and 21 dB), and 5 (29 dB). VLATME was scored 5 for transportability since it was the smallest and

TABLE 4.13

Antenna Evaluation

		BEAMWIDTH	GAIN	TRANS-PORTABILITY	COST	OMNI	TOTAL SCORE
RELATIVE WEIGHT		(3)	(3)	(3)	(2)	(1)	--
COMPANY	MODEL						
Bendix	VLATME	1	3	5	1	3	32
Hazeltine	AN/GPA-123 AN/GPA-128	3	3	4	4	3	41
Radiation Systems	1320-14B (SD)	3	2	3	4	1	33
	1320-28 (SD)	5	3	1	3	1	34
	1325-14	3	2	3	3	3	33
	1325-28	5	3	1	2	3	34
Texas Instruments	A5A	5	3	1	1	3	32
Westinghouse	AN/TPS-65	4	5	5	5	1	53

lightest. The AN/TPS-65 scored 5 since the beacon added no weight or size requirements to the system with its dual-use beacon/radar antenna. The AN/GPA-123 and AN/GPA-128 were scored 4 for small size (14 feet) and weight (100 lbs.). The RSI 1320-14B and 1325-14 scored 3 since they were 14 feet wide but weighed considerably more than the Hazeltine antennas. The 1320-28, 1325-28, and A5A antennas were scored 1 since their size and weight were much larger. It would be much more difficult to configure these antennas in a tactical application.

The AN/TPS-65, again because no extra cost is caused by a separate IFF antenna, scored 5 for cost. The Hazeltine and RSI 1320-14B antennas scored 4 because they were the next lower cost ($20K-$25K). The cost scores are roughly proportional to unit cost. Therefore, the 1320-28 ($32K) and 1325-14 ($42K) scored 3, 1325-28 ($65K) scored 2, and the VLATME ($100K) and A5A ($80K) scored 1. Integral omnidirectional antennas were desirable, although the advantage is not great. Antennas with integral omnidirectional antennas scored 3, while those without scored 1.

4.2.7.2 <u>Interrogator Results</u>

Table 4.14 summarizes the results of the IFF interrogator evaluation. The first factor considered was the number of available modes. Both the ATCBI-5 and the UPX-27 scored 5, since both units permit all possible modes (1, 2, 3/A, B, C, D, 4). Although modes B and D are not currently used in the United States, they might be used in the future. The AN/TPX-54, AN/APX-107, and Westinghouse interrogators were scored 4 because these units permit all modes except B and D. A score of 2 was given to VLATME and AN/TPX-42, since these two units lack mode 4 and VLATME also lacks mode 1.

Functional availability was determined on the basis of MTBF and MTTR. The down time for a single unit was computed by: Down Time = DT = MTTR/(MTBF+MTTR). Although the DT value is small, the overall quality and technology of a unit is reflected in its MTBF and MTTR. Scoring a 5 is the Westinghouse interrogator (DT=0.0031%), which is by far the most reliable. The AN/TPX-42A (DT=0.014%), AN/TPX-54 (DT=0.0125%), and AN/APX-107 (DT=0.0167%) were somewhat less reliable, scoring a 3. The APX-100 and UPX-27 scored a 2 with DT=0.025%. The ATCBI-5 had a DT=0.050% and scored a 1. These DT figures should not be interpreted to mean the interrogator system will be down this amount of time, since the interrogator is configured redundantly, but computed DT figures were used for comparing the units relative to each other.

TABLE 4.14

Interrogator Evaluation

		AVAILABLE MODES	RELIABILITY	TRANS-PORTABILITY	POWER OUTPUT	RECEIVER SENSITIVITY	COST	TOTAL SCORE
RELATIVE WEIGHT		(4)	(3)	(3)	(3)	(2)	(2)	
COMPANY	MODEL							
Bendix	ATCBI-5	5	1	1	4	4	3	52
	VLATME	2	2	5	1	1	5	44
Cardion	UPX-27	5	2	4	3	3	2	57
EATON/AIL	AN/TPX-42A	2	3	3	3	4	3	49
Hazeltine	AN/TPX-54	4	3	4	2	2	3	53
Teledyne	AN/APX-107	4	3	5	2	3	3	58
Westinghouse		4	5	3	3	3	1	57

Transportability is based on size and weight. VLATME and AN/APX-107 both scored a 5 since both are very small and lightweight (less than 30 lbs.). The UPX-27 and AN/TPX-54 weigh 57 and 56 pounds, respectively, and score a 4. The AN/TPX-42A and Westinghouse interrogators both weigh slightly more than 100 lbs. and have a score of 3. The heavyweight of the interrogators is the ATCBI-5 at 760 lbs, which scores a 1. The ATCBI-5 was never designed or intented to be used tactically, but could be repackaged. For comparison, all of the weights cited are based on just one unit, not the redundant configuration with switchover network.

Power output is a straightforward factor to evaluate, as the free space range of the IFF system will be proportional to the square root of the transmitted power. Having a power output of 3200 watts, the ATCBI-5 scored a 4. At 2000 watts, a score of 3 was given for the UPX-27, AN/TPX-42A, and Westinghouse interrogators. The AN/TPX-54 and AN/APX-107 have 1500 watts and were scored a 2. With only 400 watts the VLATME APX-100 interrogator scored a 1.

Receiver sensitivity is not as critical a parameter as power output, and was thus given a relative weight of 2. The ATCBI-5 (-87 dBm) and AN/TPX-42A (-86 dBm) are the most sensitive and were scored a 4. Less sensitive, scoring a 3, are the UPX-27 (-84 dBm), AN/APX-107 (-83 dBm), and Westinghouse (-84 dBm) interrogators. Scoring a 2 is the AN/TPX-54 (-80 dB), and scoring a 1 is the VLATME APX-100 (-74 dBm).

The costs, as usual, vary greatly. The lowest price, $50K (not including switchover network), is for the VLATME APX-100, which scores a 5. Scoring a 3, ranging from $110K to $140K are the ATCBI-5, AN/TPX-42A, AN/TPX-54, and AN/APX-107. More expensive still is the UPX-27 ($225K), scoring a 2. The Westinghouse ($400K) scored a 1. Not included in these estimates are costs of building switchover networks for the VLATME APX-100 and AN/APX-107.

4.2.7.3 Target Extractor Results

The Target Extractor evaluation results are summarized in Table 4.15. The Target Extractor was determined to be the most difficult unit to evaluate quantitatively, because of a wide variation in the capabilities of the different units. Some units are just basic decoders used to interface between the interrogators and the PPI displays. Some units are much more powerful (expensive) and can process both IFF and radar information. The CV-3682/UPX, for instance, provides automatic target detection for pulsed surveillance radars and IFF systems, taking some of the work load off the central computer.

TABLE 4.15
Target Extractor Evaluation

		RESOLUTION & ACCURACY	RELI-ABILITY	COST	TARGET CAPACITY	TRANS-PORTABILITY	PROCESSES RADAR	TOTAL SCORE
RELATIVE WEIGHT		(4)	(3)	(2)	(2)	(1)	(1)	
COMPANY	MODEL							
Bendix	VLATME	3	1	3	2	5	0	30
Cardion	AN/UPA-59,60	1	2	5	1	5	0	27
	KY-5035/UPX	1	3	5	1	5	0	30
	CTE-2	3	5	4	5	5	0	50
EATON/AIL	AN/TPX-42A VSP	4	3	3	4	3	0	42
Hazeltine	AN/UPA-59B	3	3	5	1	5	0	38
Litton	CV-3682/UPX	5	3	3	5	1	3	49
Sperry-UNIVAC	I-SRAP I	5	5	4	5	3	3	59
Westinghouse	DECU	4	2	3	4	3	3	42

The first factor evaluated was target position resolution and accuracy. From Table 4.11, the CV-3682/UPX and I-SRAP I have the best performance and score a 5. The AN/TPX-42A Video Signal Processor (VSP), whose range resolution and accuracy drops to 800 feet and 380 feet, respectively, scored a 4. With resolution of 1000 feet and accuracy of 250 feet the DECU also scored a 4, although the azimuth accuracy of the DECU is somewhat lower (0.7^{o}) than the others. The CTE-2, with range resolution and accuracy of 760 feet and 1000 feet, and the AN/UPA-59B, with resolution and accuracy of 800 feet and 1000 feet scored a 3. The AN/UPA-59B, however, does not produce this data digitally for all targets. The AN/UPA-59, -60 and KY-5035/UPX resolution and accuracy are PPI dependent, and were scored a 1. Also scoring a 1 is the VLATME Target Acquisition Group (TAG), which has very poor azimuth resolution and accuracy, mainly due to the VLATME antenna.

For reliability assessment the MTBF and MTTR were used to achieve a quantitative figure, Down Time, for purposes of comparison. Down Time (DT) was computed by: Down Time = DT = MTTR/ (MTBF + MTTR). The CTE-2 (DT=0.0050%) and I-SRAP I (DT=0.0040%) scored the highest with a 5. Scoring a 3 were the KY-5035/UPX (DT=0.0116%), AN/TPX-42A VSP (DT=0.0157%), AN/UPA-59B (DT=0.0088%), and CV-3682/UPX (DT=0.0111%). The AN/UPA-59, -60 (DT=0.025%), and DECU (DT=0.0206%) scored a 2, and the VLATME TAG (DT=0.050%) scored a 1.

The costs of the different systems fell into three ranges. Scoring a 5 were the AN/UPA-59 and -60 ($20K), KY-5035/UPX ($17K), and AN/UPA-59B ($15K). Scoring a 4 were the CTE-2 and I-SRAP I, both at $50K. This estimated price for the I-SRAP I is just for the beacon processor, not including the radar processor. The AN/TPX-42A VSP ($90K) scored a 3. Also scoring a 3 were the CV-3682/UPX ($234K) and DECU ($200K) since this estimated price includes the radar processing equipment.

Target capacity varied widely among candidate units. The CTE-2 (10,000 targets), CV-3682/UPX (700 targets), and I-SRAP I (250 targets) all scored a 5. The AN/TPX-42A VSP (64 targets) and DECU (64 targets) both scored a 4. The VLATME TAG target capacity is 102, but alphanumerics are displayed for only one, so it scored a 2. Scoring a 1 were the AN/UPA-59 and -60, KY-5035/UPX, and AN/UPA-59B since these units display alphanumeric readouts on only one target (expandable only to several).

These decoders, however, all scored well on transportability. Scoring a 5 are the VLATME, AN/UPA-59 and -60, KY-5035/UPX, CTE 2, and AN/UPA-59B, all having weights of 40 pounds or less. The AN/TPX-42A VSP (90 lb) and I-SRAP I (100 lb) scored a

3. At 230 lb the DECU scored a 3, because this weight includes the radar processing. The CV-3682/UPX weight (550 lb) also includes the radar data processor and this unit scored a 1. The last factor evaluated was whether the unit had capabilities for processing and correlating the radar information. This was rated as either 0 or 3. The CV-3682/UPX, I-SRAP I, and DECU do have this capability.

4.2.8 ATCRBS INVESTIGATION SUMMARY

The IFF system, because of its many advantages over conventional radar, has been designated the primary aircraft sensor for the MATCALS mission. Because of the importance of the beacon system, baseline requirements were needed and developed (see Table 4.7). Off-the-shelf vendor data describing current systems were solicited from the manufacturers (Tables 4.8 through 4.11). Evaluation of these data was made (Tables 4.13 through 4.15), and a summary of the vendor products and the evaluated scores are presented in Table 4.16. From this table and the proceeding discussions the following conclusions are drawn.

The antenna scoring highest is the Westinghouse system, mainly because it is an integral common antenna for both the radar and beacon. A prerequsisite for using this antenna might be that the TPS-65 radar be the ASR. If the TPS-65 were used, it makes little sense to acquire a separate beacon antenna. If this not be the case, the Hazeltine antennas are the next best choice since they are small, light, and thus very tactical. Also the reduced weight would put less demand on the ASR drive motor, since all the antennas, except the Bendix VLATME ride "piggyback" on the ASR antenna. The 28 foot antennas might be more difficult to deploy tactically. The RSI 1320-14 is a good alternative to the Hazeltine antennas.

The Teledyne AN/APX-107 scored the highest among the interrogators, mainly because of its extremely small size. However, there are factors which when considered might make it not quite so desirable in the MATCALS mission. It currently is not deployed in a redundant configuration, requiring that a switchover network be developed. The range performance does not meet the MATCALS requirement because of memory limitations, which could be expanded. More compatible candidates are the Cardion AN/UPX-27, Hazeltine AN/TPX-54, and Westinghouse interrogators. These three systems rate approximately the same. The AN/UPX-27 is currently being used by the Marine Corp, an inventory benefit not considered in this evaluation. The older EATON/AIL AN/TPX-42 rates lower and does not include Mode 4 capability. The Bendix

TABLE 4.16
Summary of Vendor Products and Evaluation Scores

COMPANY	ANTENNA		INTERROGATOR		TARGET EXTRACTOR	
Bendix	- VLATME	 32	ATCBI-5 VLATME APX-100	52 44	- VLATME TAG	 30
Cardion	-		AN/UPX-27	57	AN/UPA-59 AN/UPA-60 KY-5035/UPX CTE-2	27 27 30 50
Eaton/AIL	-		AN/TPX-42,TSDA	49	AN/TPX-42 VSP	42
Hazeltine	AN/GPA-123 AN/GPA-128	41 41	AN/TPX-54	53	AN/UPA-59B (V2)	38
Litton	-		-		CV-3682/UPX	49
Radiation Sys.	1320-14 B (SD) 1320-28 (SD) (1325-14) 1325-28	33 34 33 34	-		-	
Sperry Univac	-		-		I-SRAP I	59
Teledyne	-		AN/APX-107	58	-	
Texas Inst.	A5A	32	-		-	
Westinghouse	Yes	53	Yes	57	DECU	42

Number on right side of column is relative score

ATCBI-5 is not intended for tactical use, but even so, scored well. The VLATME APX-100 has limited range performance and does not have Mode 4 capability.

The highest scoring target extractor is the Sperry Univac I-SRAP I. One should also consider the Cardion CTE-2, Litton CV-3682/UPX, EATON/AIL AN/TPX-42 VSP, and Westinghouse DECU. The I-SRAP I, CV-3682/UPX, and DECU all have capabilities for radar/IFF correlation. The CV-3682/UPX is probably the most powerful since it has tracking capabilities. Another powerful unit is the I-SRAP I, which is similar to the SRAP I currently being deployed by the FAA. If the TPS-65 were selected as the ASR, the DECU would be the logical choice, for reasons of design compatibility. The AN/TPX-42 VSP is an older system which has been widely used in both tactical and and non-tactical applications.

One must appreciate the limitations to this evaluation, which did not consider the impact of other parameters of the MATCALS systems such as commonality with other MATCALS subsystems, set-up time, life cycle costs, test equipment needed, and use of some of these IFF subsystems in other Naval and Marine Corps systems. The unit scores should be considered estimates; and with any subjective analysis, there will be some associated margin for variation. However, this ATCRBS evaluation should be useful for identifying those subsystems which deserve further analytical considerations.

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SECTION 5
CONCLUSIONS AND RECOMMENDATIONS

The tasks Georgia Tech performed in this MATCALS investigation divide naturally into two general areas: AN/TPN-22 improvement investigations and air traffic control system evaluation. The most significant conclusion/recommendation for the three tasks involving the AN/TPN-22 is that flight tests are still required to bring these task efforts to fruition. The air traffic control investigations require more detailed evaluation of candidate systems, for both original and relaxed versions of MATCALS baseline performance specifications.

The proposed flight tests will, through the use of the multipath interference fence and the special corner reflector mounted in the aircraft, help to isolate the sources of tracking error to the phenomenology involved. These flight tests, therefore, should determine conclusively the factors limiting the tracking accuracy of the AN/TPN-22 as well as that accuracy limit.

The television tracker system was assembled and tested at Georgia Tech and then installed at the MATCALS test site at Patuxent NAS. The same flight test program referenced above will also serve to evaluate its performance. Upgrades of the TV tracker system capability will be determined during this flight test.

Several conclusions from the AN/TPN-22 technical assistance provided to NESEA are discussed in Section 3 of this report. The three most important of these are: (1) multipath interference appears to be a major tracking error source at both very long and very short ranges; (2) the GAGC circuitry has been observed to be malfunctioning; and (3) amplitude processing techniques appear to offer significant advantages over the thresholding technique presently used.

Georgia Tech recommends that the gated AGC process be completely reevaluated for the TPN-22 application. The flight test program is designed to provide data which will answer multipath interference questions and to gather amplitude data which may be used to evaluate different amplitude processing techniques. Once a promising candidate processing approach is identified, Georgia Tech further recommends that a study be initiated to optimize the implementation of that technique for use in the AN/TPN-22. That study would include investigation of real-time programming options, approximation techniques, and hardware approaches to implementing the candidate amplitude processing technique.

The air traffic control investigation for MATCALS included evaluations of candidate airport surveillance radar and radar beacon systems, as documented in Section 4 of this technical report. Vendor information was tabulated and evaluated with regard to baseline performance specifications.

Four militarized airport surveillance radar systems and three variants were modeled for computation of detection range performance within the specified MATCALS coverage volume using original and relaxed criteria for detection. None of the radar systems evaluated meets either the original or the relaxed detection criteria throughout the specified coverage volume.

The GPN-24 and TPN-24 are range limited in both clear air and rain scenarios. The TPS-44 has better detection performance in comparison, but has no capability to reject rain backscatter alarms. The TPS-65 has almost adequate range performance, but is susceptible to target fallout due to multipath interference effects that are most severe at 10,000 foot aircraft altitudes.

Georgia Tech recommends that the MATCALS airport surveillance radar detection performance specifications indicate an 80 percent detection probability and a 10^{-6} false alarm rate over 60 nautical miles of range. One to 30 degree elevation angle coverage and an aircraft ceiling of 30,000 feet appear adequate for a MATCALS terminal area surveillance radar system.

Georgia Tech further recommends that the MATCALS ASR include a modular, solid state transmitter typified by the TPS-65 variants. Such a transmitter concept offers characteristics of graceful degradation, does not need water cooling, and may not need FAA certification for CONUS operation. If the antenna characteristics of the TPS-65 with 50 kW solid state transmitter were modified to mitigate multipath interference susceptibility, that system would be the clear choice of those evaluated.

An analogous baseline performance specification was established for the MATCALS radar beacon system, but the essential content of this baseline was dictated by the overall requirement for FAA system compatibility. The vendor data were tabulated into three hardware categories: antenna, interrogator, and target extractor. Each category was evaluated separately through quantitative assessment of vendor equipment's applicability to the MATCALS mission.

The highest scoring antenna is the Westinghouse system, a conclusion based on antenna commonality with the AN/TPS-65 radar. The Teledyne AN/APX-107 scored highest among the interrogators, but some system development would be required to

meet all MATCALS ATCRBS requirements. In lieu of this system, the Cardion AN/UPX-27, Hazeltine AN/TPX-54, and Westinghouse interrogators scored approximately the same, and all are MATCALS compatible. The highest scoring target extractor is the Sperry Univac I-SRAP I, although several other systems also scored well: the Cardion CTE-2, the Litton CV-3682/UPX, the EATON/AIL AN/TPX-42 VSP, and the Westinghouse DECU.

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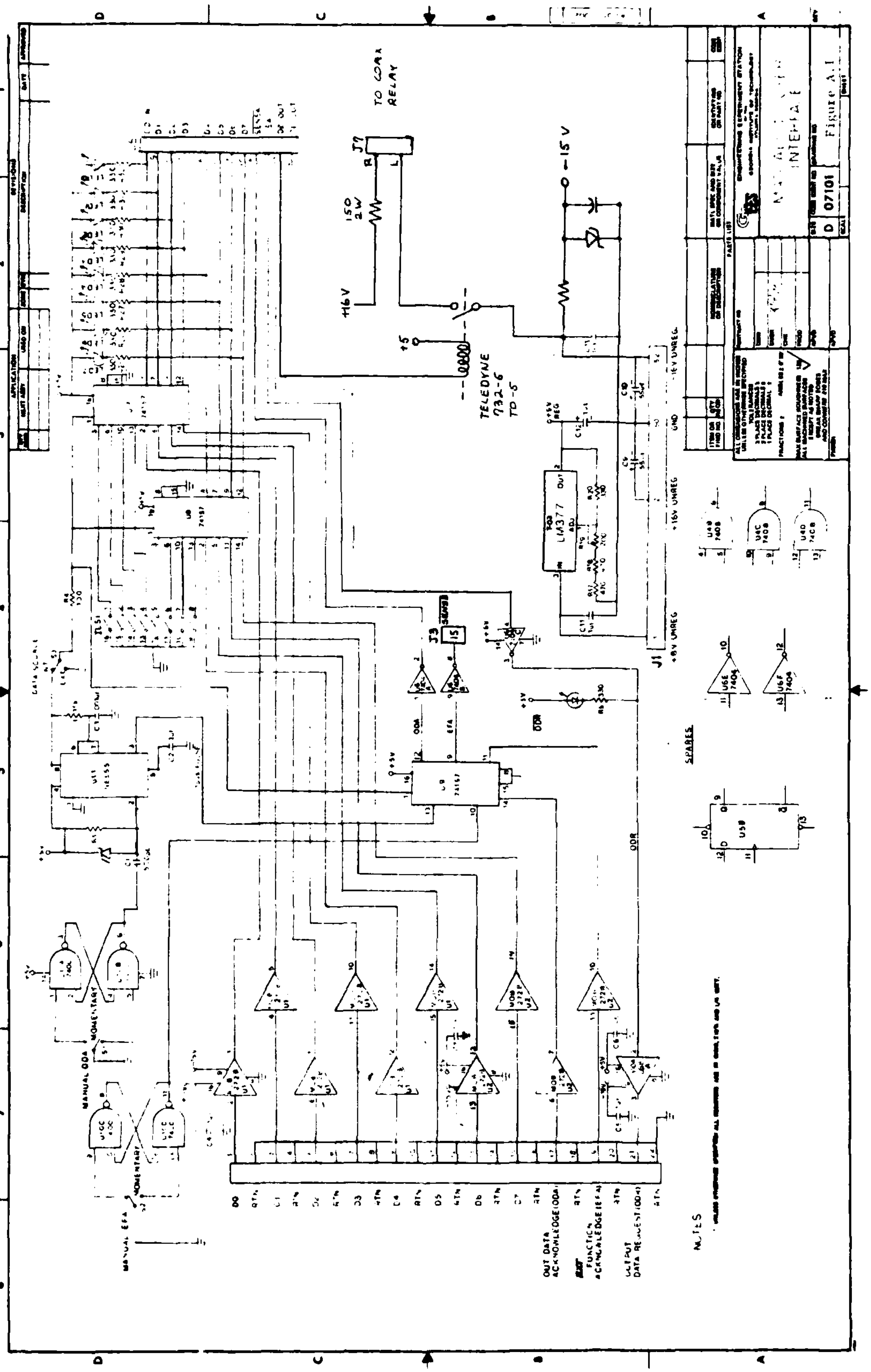
APPENDIX A

AN/UYK-20 TO TV-TRACKER HARDWARE INTERFACE

Figure A.1 depicts a schematic diagram of the hardware interface referenced in Section 3 of this report. This brief interface description defines on-line and off-line operations. Note that on-line or off-line modes may be selected by switch S3.

During on-line operations logic levels are translated from NTDS to TTL (and conversely from TTL to NTDS) by interface receivers (drivers, in opposite direction) U1 and U2 (U3). In addition the relay switch which selects the routing of the camera video signals is controled by U5A and the Q1-Q2 driver circuit. The audio driver Q3 and the loudspeaker are not presently designated for use.

During off-line operations handshaking signals can be manually controlled with S1 and S2. Data can be manually entered by DIP switch DS1.


TO CORA RELAY
J7
150 2W
+16V
+5
TELEDYNE 732-6 TO-5
-15 V
LM377
J1
J3
SPARES
NOTES
D 07101
Figure A.1

APPENDIX B

BASELINE SPECIFICATIONS FOR MATCALS AIRPORT SURVEILLANCE RADAR

The MATCALS Air Surveillance Radar (ASR) Baseline sources are:

No.	Code	Meaning
1	SOR	Specific Operational Requirement 34-22
2	M-P/O	MATCALS Project Office (NAVELEX)
3	GIT	Georgia Institute of Technology
4	GIT/TPS-65	GIT selected from AN/TPS-65 Specification ELEX-R-332
5	GIT/RHB	GIT selected from the Radar Handbook by Skolnik

The parameter choices are, where necessary, rationalized in the paragraphs following the table.

	Description	Condition or Value	Source
1.0	General		
1.1	ASR Existence	Yes	SOR
1.2	ASR Priority	Back up to Beacon and TADIL	SOR
1.3	Data Correlation	Beacon and TADIL	SOR
1.4	Aircraft controlled	40 minimum	SOR
1.5	Aircraft pass through	50 minimum	SOR
1.6	Compatibility	FAA, U.S. and Allied Armed Forces	SOR
1.7	Air Defense Role	None	M-P/O
1.8	Low Probability of Intercept	Not required	M-P/O
1.9	Electronic countermeasures	Not required	M-P/O
2.0	Coverage		
2.1	Range	60 nmi (MAX)	SOR
		0.5 nmi (MIN)	M-P/O
2.2	Azimuth	0-360 Degrees continuous	SOR
2.3	Elevation	1/2-40 Degrees	M-P/O
2.4	Altitude	40 kft Maximum	M-P/O
3.0	Weather Models		
3.1	Rain Rates		
	3.1.1 Light rain in total approach volume*	4 mm/hr	GIT

* Approach volume is bounded by a maximum range of 60 nmi, minimum range of 0.5 nmi, 360 degrees in azimuth, radar elevation angles of 0.5 to 40 degrees and altitude of 40,000 feet.

3.1.2	Medium rain - In ten mile radius rain cell in approach volume	25 mm/hr		SOR+
3.1.3	Heavy rain in five mile radius rain cell in approach volume	50 mm/hr		GIT
3.1.4	Rain is uniformly distributed to altitude of 6096 m (20,000 ft.) and fills the azimuth and range resolution cells	----		GIT/TPS-65 page 22
3.1.5	Wind shear model is 8.4A in m/sec/km where A is the altitude in kilometers up to kFT	----		GIT
3.1.6	Rain Attenutation			
	3.1.6.1 - 1 GHz			
	3.1.6.1.1	4 mm/hr	.000469 dB/km	RHB (p24-25)
	3.1.6.1.2	25 mm/hr	.00496 dB/Km	RHB (p24-25)
	3.1.6.1.3	50 mm/hr	.008 dB/km	RHB (p24-25)
	3.1.6.2 - 3 GHz			
	3.1.6.2.1	4 mm/hr	.0009 dB/km	
	3.1.6.2.2	25 mm/hr	.0073 dB/km	
	3.1.6.2.3	50 mm/hr	.0149 dB/km	
	3.1.6.3 - 9 GHz			
	3.1.6.3.1	4 mm/hr	.06 dB/km	RHB (p24-25)
	3.1.6.3.2	25 mm/hr	1.26 dB/km	RHB (p24-25)
	3.1.6.3.3	50 mm/hr	2.8 dB/Km	RHB (p24-25)
3.1.7	Rain Backscatter (Reflectivity N $\bar{\sigma}$ = η)			
	3.1.7.1 - 1 GHz			
	3.1.7.1.1	4 mm/hr	2.22 E-11 m^2/m^3	MP/O
	3.1.7.1.2	25 mm/hr	3.33 E-10 m^2/m^3	MP/O
	3.1.7.1.3	50 mm/hr	9.99 E-10 m^2/M^3	MP/O
	3.1.7.2 - 3 GHz			
	3.1.7.2.1	4 mm/hr	1.44 E-9 m^2/m^3	MP/O
	3.1.7.2.2	25 mm/hr	2.7 E-8 m^2/m	
	3.1.7.2.3	50 mm/hr	8.2 E-8 m^2/m^3	MP/O
	3.1.7.3 - 9 GHz			
	3.1.7.3.1	4 mm/hr	1.3 E-7 m^2/m^3	B STAR*
	3.1.7.3.2	25 mm/hr	2.6 E-6 m^2/m^3	RHB (24-30)
	3.1.7.3.3	50 mm/hr	7.8 E-6 m^2/m^3	RHB (24-30)

* For 9 GHz the value at 4 mm/hr from the GIT (Battlefield Surveillance and Target Acquisition Radar) report was scaled by the 6th power of the drop size ratio of the peak percentage line from Table 8, RHB, p24-24.

\+ Specified for PAR only, applied to ASR by implication.

4.0	<u>Target Model</u>		
4.1	Swerling Case 1 or 3	1.0 m^2 (MEAN)	GIT
4.2	Speeds	0-MACH .99	M-P/O
5.0	<u>Land Clutter Model</u>		
5.1	Log-normal distributed	--	GIT/TPS-65
5.2	Median Value	-34 dB (m^2/m^3)	GIT/TPS-65
5.3	95th percentage	-18 dB (m^2/m^3)	GIT/TPS-65
6.0	<u>Multipath Model</u>		
6.1	Blake's model (NRL report 6930, section 6)	---	GIT
7.0	<u>Detection Models</u>		
7.1	Detection probability per scan*	0.9	M-P/O
7.2	False alarm rate	1 x 10^{-7} per scan	M-P/O
7.3	Swerling Case One	independent between scans	RHB
7.4	Swerling Case Three	independent pulse to pulse	RHB
8.0	<u>Track Continuity</u>		
8.1	Continuous for aircraft that (1) Match target model (2) are within coverage volume and (3) have a radar elevation angle of plus 1/2 degree relative to radar horizon	Elevation angle 1/2 degree	M-P/O
9.0	<u>Antenna Rates</u>		
9.1	Rate	6 to 15 rpm	M-P/O
9.2	Scan Type	Mechanical	GIT
10.0	<u>Resolution</u>		
10.1	Range resolution	200 - 500 feet	GIT
10.2	Azimuth resolution	2-3 degrees	GIT
10.3	Elevation resolution	3D not required	M-P/O

* Desired for any combination of target, weather and clutter models. Required for clear weather.

11.0 Accuracy

11.1	Range accuracy	100 feet	GIT
11.2	Azimuth accuracy	0.1 degree	GIT
11.2	Elevation accuracy	3D not required	M-P/O

12.0 Beam Shape

12.1	Elevation	csc^2 to 40^0	M-P/O
12.1	Azimuth	2-3 degrees	GIT

13.0 Frequency Regions of Prime Interest

13.1	Low	1.1 to 1.3 GHz	GIT
13.2	High	2.7 to 2.9 GHz	GIT

14.0 Atmospheric Attenuation

14.1	Low Frequency	0.005 dB/km	GIT/RH
14.2	High Frequency	0.007 dB/km	GIT/RH

The following paragraphs discuss the origins of and the reasons for selecting these ASR Parameters.

1.0 General

1.1 thru 1.6
SOR directed
1.7 thru 1.9

The MATCALS program office dictated that the ASR will have no AD, LPI, or ECM roles.

2.0 Coverage

2.1 Range

Minimum range of 0.5 nmi was selected to be consistant with radar capabilities and other ASR specifications.

2.2 Azimuth - SOR

2.3 Elevation

M-P/O selected. Consistant with radar capabilities. Consistant with other ASR specifications.

2.4 Altitude

M-P/O selected at 40 kft minimum. Consistant with operation of aircraft in the approach volume.

3.0 Weather Model

3.1.1 Light Rain

GIT selected 4 mm/hr as the standard moderate rain that could extend throughout the aproach volume. This value is consistant with that used through the radar field.

3.1.2 Medium Rain - SOR

3.1.3 Heavy Rain

GIT selected after review with MATCALS program office.

3.1.4 Rain, Vertical Distribution

GIT followed the AN/TPS-65 specification and defined a uniform distribution rain distribution to 20,000 feet altitude.

3.1.5 Wind Shear

GIT defined a uniform rate of change of wind shear velocity versus altitude. This wind mode was selected to give zero velocity at the ground and 100 mph at 20,000 feet. The coefficient is 5 mph/k feet of altitude.

4.0 Target Model

4.1 Swerling Case One or Three

Dependent on radar frequency suite. The value of 1.0 m^2 is the correct magnitude for a small aircraft in cruise trim viewed nose-on.

4.2 Aircraft speeds

0 to MACH .99 MACH was selected by M-P/O.

5.0 Land Clutter Model

The land clutter model was selected by GIT from the TPS-65 specification.

6.0 Multipath Model

GIT will use Blake's model for multipath as developed in NRL Report 6930 and programmed in the GIT radar range estimation program.

7.0 Detection Models

GIT will assume a specification for a per scan PD of 0.9, PFA of 1×10^{-7}, and Swerling Case 1 or 3 target. These values apply for the full approach volume.

8.0 Track Continuity

GIT will require specification of continuous track of targets which match or exceed the target model.

9.0 Antenna Rates

From the AN/TPS-65 specification, GIT selected antenna azimuth scan rates of 6 to 15 rpm.

10.0 Resolution

The range and angle resolution should be chosen for the best balance between several conflicting desires. These desires include:

(1) The smallest azimuthal beamwidth possible in order to resolve close targets and to reduce clutter.
(2) The least cost antenna which will perform the necessary functions.
(3) The highest gain antenna that is feasible.
(4) The shortest range resolution compatible with data processing limitations.
(5) Sufficient range and angle resolution to allow the ASR the accuracy needed to control aircraft in near proximity or on terminal approach.
(6) An antenna of size and mass which can be routinely disassembled and moved with tactical support equipments.

For L- or S-band radars, range resolutions in the 200 - 500 foot range and azimuthal resolutions in the 2-3 degree range are acceptable.

11.0 Accuracy

Practical experience indicates that a well calibrated radar will have range biases on the order of 20 to 100 feet. Therefore a range accuracy goal of 100 feet was selected.

With reasonable calibration, the angle accuracy can be .1 degree.

12.0 Beam Shape

The MATCALS program office indicated that cover to 40° elevation was required and that separate elevation beams were not required. The elevation pattern shall be shaped to yield acceptable aircraft detection up to 40,000 feet and 60 n.m.i. range, and above 1/2 degree above the horizon.

13.0 Frequency Regions of Prime Interest

Prior systems and frequency allocations for ASR radars are concentrated in these frequency regions. Above 3 GHz the atmospheric attenuation rises rapidly. For these reasons GIT has selected these two frequencies as the frequencies of prime interest.

14.0 Atmospheric Attenuation

GIT selected these values as representative, from the radar handbook edited by Skolnik.

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APPENDIX C

BASELINE SPECIFICATIONS FOR MATCALS RADAR BEACON SYSTEM

The MATCALS Radar Beacon Baseline sources are:

No.	Code	Meaning
1	SOR	Specific Operational Requirement 34-22
2	M-P/O	MATCALS Project Office (NAVELEX)
3	GIT	Georgia Institute of Technology
4	FAA	FAA order 1010.51A, U. S. National Standard for the IFF Mark X (SIF)/ Air Traffic Control Radar Beacon system characteristics

	Description	Condition or Value	Source
1.0	General		
1.1	Sensor Priority	Primary Sensor	SOR
1.2	Data Correlation	TADIL and ASR	SOR
1.3	Aircraft Controlled	40 minimum	SOR
1.4	Aircraft Pass Through	50 minimum	SOR
1.5	Compatibility	FAA, U. S., and Allied Armed Forces	SOR
1.6	Available Modes	1, 2, 3/A, B, C, D, (4 compatible)	FAA, M-P/O
1.7	Preferred Modes	3/A, C	SOR
1.8	Redundancy	Required	SOR, FAA
2.0	Coverage		
2.1	Range	200 nmi (max.) 1 nmi (min.)	M-P/O

	Description	Condition or Value	Source
2.2	Azimuth	0-360 degrees continuous	SOR/FAA
2.3	Elevation	1/2 - 45 degrees	FAA
2.4	Altitude	40 kft maximum	M-P/O
3.0	Accuracy		
3.1	Range Accuracy	±1,000 feet	FAA
3.2	Azimuth Accuracy	±1.0 degree	FAA
3.3	Altitude	within ±125 feet, on a 95% probability basis	FAA
4.0	Beam Shape		
4.1	Elevation	1/2 to 45 degrees above horizontal plane	FAA
4.2	Azimuth	3 degrees	FAA
4.3	Side and back lobe radiation	at least 24 dB below peak of main lobe radiation	FAA
5.0	Polarization		
5.1	Interrogation and Reply Transmissions	Vertical	FAA
6.0	Rain Rates		
6.1	Light rain in total approach volume*	4 mm/hr	GIT

*Approach volume is bounded by a maximum of 200 nmi, minimum of 1.0 nmi, 360 degrees in azimuth, radar elevation angles of 0.5 to 45 degrees and altitude of 40,000 feet.

	Description	Condition or Value	Source
6.2	Medium rain in ten mile radius rain cell in approach volume	25 mm/hr	SOR+
6.3	Heavy rain in five mile radius rain cell in approach volume	50 m[illegible]	GIT
6.4	Rain is uniformly distributed to altitude of 6,096 m (20,000 ft) and fills the azimuth and range resolution cells		GIT
7.0	<u>Antenna Scan Rates</u>		
7.1	Rate	6 to 15 rpm	M-P/O
7.2	Scan Type	Mechanical, locked to ASR antenna	GIT
8.0	<u>Interrogation Frequency</u>		
8.1	Center Frequency	1,030 MHz	FAA
8.2	Frequency Tolerance	± 0.2 MHz	FAA
9.0	<u>Interrogation Modes</u>		
9.1	Transmitted Pulses	P_1 and P_3	FAA
9.2	Control Pulse	P_2, between P_1 and P_3	FAA
9.3	Mode Spacing Between P_1 and P_3		
9.3.1	Mode 1	3 ± 0.1 μ sec.	FAA

+ Specified for PAR only, applied to ASR and beacon by implication.

Description		Condition or Value	Source
9.3.2	Mode 2	5 $\pm$0.2 µsec.	FAA
9.3.3	Mode 3/A	8 $\pm$0.2 µsec.	FAA
9.3.4	Mode B	17 $\pm$0.2 µsec.	FAA
9.3.5	Mode C	21 $\pm$0.2 µsec.	FAA
9.3.6	Mode D	25 $\pm$0.2 µsec.	FAA
9.4	Interval Between P_1 and P_2	2.0 $\pm$0.15 µsec.	FAA
9.5	Duration of Pulses P_1, P_2, and P_3	0.8 $\pm$0.1 µsec.	FAA
9.6	Rise Time of Pulses P_1, P_2, P_3	Between 0.05 and 0.1 µsec.	FAA FAA
9.7	Decay Time of Pulses P_1, P_2, P_3	Between 0.05 and 0.2 µsec.	FAA
10.0	Interrogation and SLS Transmission		
10.1	Sidelobe Suppression (SLS) Capability	Required	FAA
10.2	Radiated Amplitude of P_2	Greatest sidelobe for P_1, lower than 9 dB below main beam P_1	FAA
10.3	Radiated Amplitude of P_3	Within 1 dB of main beam P_1	FAA
11.0	Interrogator - Receiver		
11.1	Repetition Frequency	450 per second (max.)	FAA
12.0	Power Output		
12.1	Effective Radiated Peak Power of Interrogation Pulses (P_1 and P_3)	52.5 dBW (for 200 nmi range), may be reduced for particular site requirements	FAA

	Description	Condition or Value	Source
13.0	Receiver Sensitivity		
13.1	Maximum Receiver Sensitivity	85 dB below one milliwatt	FAA
13.2	Sensitivity Time Control (STC) for Short Ranges	Adjustable between 30 and 50 dB below maximum sensitivity	FAA
13.3	Recovery Rate	6 dB for each doubling of range	FAA
14.0	Receiver Bandwidth		
14.1	Center Frequency	1,090 MHz	FAA
14.2	Bandwidth at 40 dB below Maximum Sensitivity	24 MHz	FAA
15.0	Spurious Emissions and Responses		
15.1	Spurious Radiation of Interrogator	76 dB below one watt	FAA
15.2	Spurious Response to Signals Outside Bandpass	60 dB below maximum sensitivity	FAA

The following paragraphs are in reference to the beacon parameters specified previously.

Coverage

2.1 Range

FAA order 1010.51A specifies range limits of from 1 to 200 nmi, although interrogators having more limited range may be employed at many locations. M-P/O has set a minimum desired radar range of 0.5 nmi, but this may not be achievable with a conventional beacon system.

2.2 Elevation

FAA order 1010.51A specifies elevations from 1/2 to 45 degrees above the horizontal plane, although M-P/O has designated only 1/2 to 40 degrees elevation.

2.4 Altitude

FAA ofer 1010.51A specifies that Mode C provide automatic pressure-altitude data transmission in 100-foot increments from -1,000 feet to 126,700 feet.

8.0 Interrogation Frequency

8.2 FAA order 1010.51A specifies that the center frequencies of the control transmission and each of the interrogation pulse transmissions shall not differ from each other by more than 0.2 MHz.

12.0 Power Output

12.1 Effective Radiated Peak Power

The effective radiated power includes the antenna gain and transmission line losses. The 52.5 dBW specified is for a maximum range of 200 nmi Provision must be available to reduce the transmitted power when operating in a restricted range environment.

13.0 Receiver Sensitivity

13.1 Maximum Receiver Sensitivity

This value is for a 200 nmi capability. For this receiver sensitivity requirement, a nominal 3 dB transmission line loss and an antenna gain of 21 dB are assumed.

13.2 Sensitivity Time Control (STC)

The STC reduces receiver sensitivity at short ranges to minimize reply path reflections and pulse spacing. FAA order 1010.51A specifies that 15.36 μsec. after the leading edge of P_3 (1 nautical mile plus transponder delay), the gain shall be reduced to an adjustable value between 10 and 50 dB below maximum sensitivity. Also, the recovery rate shall be adjusted to suit local conditions.

13.3 Recovery Rate

This follows the initial reduction of sensitivity at 15.36 μsec. after the leading edge of P_3.

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